GEOLOGY OF A PORTION OF THE SOUTHERN SIERRA NEVADA OF CALIFORNIA: THE NORTHERN KERNVILLE QUADRANGLE.

by

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A thesis presented to the Division of the Geological Sciences of the California Institute of Technology in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

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ABSTRACT.

The northern Kernville quadrangle lies on the great central plateau of the southern Sierra Nevada in Tulare, Kern, and Inyo counties, California. It comprises about 600 square miles.

Geomorphically, the area consists of a great interior platform, bounded on the east by the Sierran escarpment and Sierra Nevada fault, and on the west by the Main Fork of the Kern river. The region is divisible into nine geomorphic provinces, each with distinct characteristics. From west to east, these are: (a) the Greenhorn mountains, a range averaging 7000 feet in elevation, whose summits are remnants of an ancient erosional level, (b) the Main Fork valley, a pronounced north-south valley of 3000 foot depth, traversing the entire quadrangle, (c) the Meadowlands, a high, rolling oldland, remnant of an old erosional surface, (d) the South Fork canyon, (e) the Rockhouse basin, (f) the Crestal Upland, which marks the eastern crest of the Sierra Nevada, (g) the South Fork valley, a wide, alluviated east-west valley, which bisects the area in an east-west direction, (h) Kiavah mountain, and (i) Piute mountain. The origin of each of these subdivisions is discussed. It is shown that a complex series of events produced the present geomorphic features. The region has undergone planation, rejuvenation in at least two epochs, and subsequent erosion to the present time. A geomorphic history attempts to harmonize all recorded events.

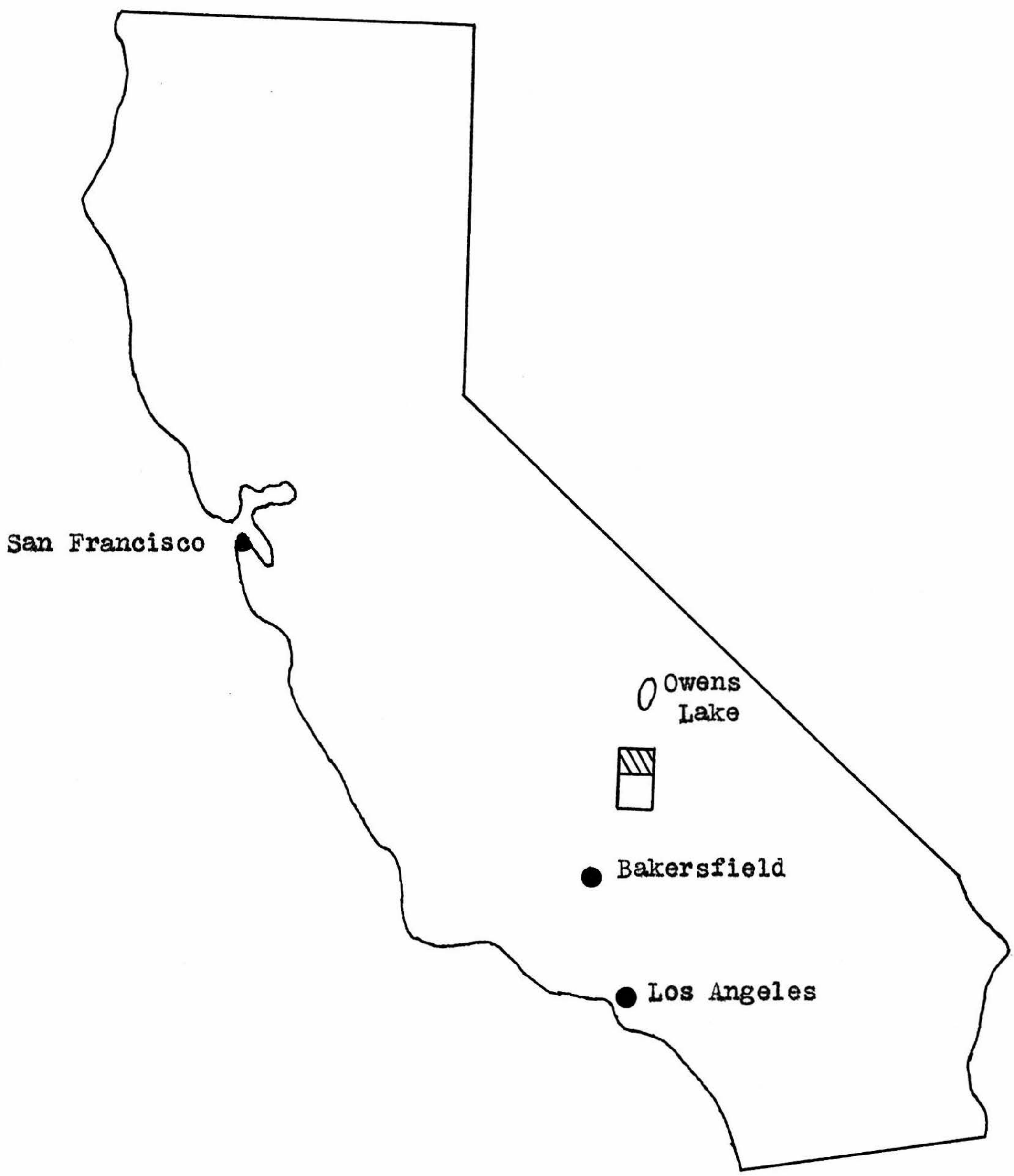
Structurally the region contains the important Kern Canyon fault, which parallels the Main Fork of the Kern for a distance of more than fifty miles, although not strictly coincident with it. It is shown that the Kern Canyon fault is of very ancient date, probably pre-Pliocene, also that a high fault-line scarp is eroded along the Kern Canyon fault. Evidence is presented to explain the discordance of the Main Fork of the Kern river with the fault. It is suggested that superposition by alluviation prevented the river from taking a course along the fault, as the stream was revived.

Petrologic and field studies in the area show the following rock units to be present: (1) a series of metamorphic rocks of probable Carboniferous age, classed as the Kernville series, composed primarily of quartzites, phyllites, schists, and marbles; these are invaded by (2) an hornblende-gabbro to biotite-gabbro, which is closely associated with (3) a quartz-diorite, which invades the gabbro. The date of emplacement of these units is suggested as late Carboniferous. (4) The Isabella granodiorite, varying to granite, invaded all the other formations, and is the final important intrusive unit. This invasion probably accompanied the major diastrophic disturbance of the Sierra, generally set at late Jurassic to early Cretaceous. Tertiary and Quaternary lavas preserve erosional surfaces formed across the crystalline units. Some swamp and lake deposits, together with present and older alluvium, complete the petrologic sequences.

Economically, the region has few deposits of commercial importance. Gold and barite have been mined commercially. Future production is improbable.

INTRODUCTION.

Figure 1.



Index Map, State of California,
Showing Location of Kernville Quadrangle.

INTRODUCTION.

Purpose, Selection, and Scope of the Study.

The study of the northern Kernville quadrangle as a sample area of southern Sierra Nevada geology was undertaken to provide basic material for a thesis for the degree of Doctor of Philosophy in Geology at the California Institute of Technology. The problem was suggested by Professor W. J. Miller, of the University of California at Los Angeles. The thesis consists of a complete treatment of the general geology, with special emphasis on petrology and petrologic problems.

Field Work and Field Methods.

A reconnaissance of the general region was made in the fall of 1933; work was continued at intervals throughout the spring of 1934. Detailed work on the areal map began in the summer of 1934, and was continued in the summer of 1935. Subsequent trips were made to the region in the winter of 1935-36, and fall 1936. In all, over nine months were spent in active field work.

In the summer of 1934, a base camp was established on Kennedy meadows, on the South Fork of the Kern river. (Plate XVI.) This base camp offered ready accessibility to the heart of the area, Rockhouse basin and the Domelands. In the summer of 1935, a base camp was established on Horse meadows, on the headwaters of Salmon creek. Sub-base camps were occupied for various lengths of time at Taylor meadows, Bartolas flats, Rockhouse basin, Woodpecker meadows (head of Trout creek), and Little Round meadow. Other camps were established for shorter periods in various parts of the region.

A three week rapid reconnaissance survey of the Olancha quadrangle was made for the purpose of comparing geological problems in it and the Kernville region.

On the geologic map accompanying this report, the geology of Tulare and Inyo counties is by the writer; that of Kern county, modified, after W. J. Miller. (See map in pocket.)

Unfinished Work.

In all, three-fourths of the area of the Kernville quadrangle has been mapped. The completion of the map, accompanied by a survey of the mineral resources of the quadrangle is soon to be finished by W. J. Miller, of the University of California at Los Angeles, and the writer, who expect to publish this survey in the near future. It has also been planned to carry on further investigations of the geomorphology, and of the volcanic geology of this and the Olancha quadrangle, with Mr. Robert P. Bryson of this institution.

ACKNOWLEDGMENTS.

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In the completion of a study of this type one contacts many persons who have extended courtesies in the course of the work. To all of these the writer expresses his appreciation.

In particular, the writer wishes to thank all of the members of the staff of the Division of the Geological Sciences of the California Institute of Technology for making the presentation of this work possible. Special thanks is due Dr. Ian Campbell, Associate Professor of Petrology, who gave hours of his time in aiding all phases of the work, and under whom the major work was conducted. To Dr. J. P. Buwalda, Professor and Chairman of the Division of the Geological Sciences, the writer owes the privilege of conference on the thesis, and related problems, and for constant advice during his stay at the Institute. To Dr. George H. Anderson, Curator of Geology at the California Institute, and former colleague of the writer, he owes thanks for critical and friendly advice offered on many of the thesis and general problems. The entire faculty of the Division, and numerous graduate students, have aided by discussions and suggestions.

To Dr. W. J. Miller, Professor and Chairman of the Department of Geology of the University of California at Los Angeles, and colleague of the writer, he owes the suggestion of the problem, and thanks for constant advice and encouragment, both in the field and in the preparation of this manuscript.

Dr. Catherine Campbell read the entire physiographic and structural sections of the thesis, and offered many excellent suggestions on its preparation.

To Dr. F. E. Matthes, of the United States Geological Survey, the writer owes thanks for a long conference on the general problems of the Sierra Nevada, with which Dr. Matthes is particularly familiar.

Mr. Robert P. Bryson, graduate student in the Division of Geological Sciences of the California Institute, accompanied the writer during two field seasons, and contributed invaluably to the preparation of this manuscript and to the problems and their solution in the region. In addition, most of the photographic work of the thesis was done by Mr. Bryson.

The writer was assisted in the field in the summer of 1935 by Mr. Thomas Donlon and Mr. W. Ross Cabeen, students in the Department of Geology of the University of California at Los Angeles.

Many residents of the area offered assistance in the field work. In particular, thanks are due Mrs. Cliff Willoughby, of the Porter Ranch, Brown, California; and to Mr. Charles Andress, of Weldon, California.

Finally, the writer wishes to thank his colleagues, Miss. Myrta Lisle McClellan, Assistant Professor of Geography; Dr. Frederick C. Leonard, Associate Professor and Chairman of the Department of Astronomy; and Dr. Joseph Murdoch, Assistant Professor of Geology; all of the University of California at Los Angeles, for constant mental stimulation and friendly assistance.

GEOMORPHOLOGY.

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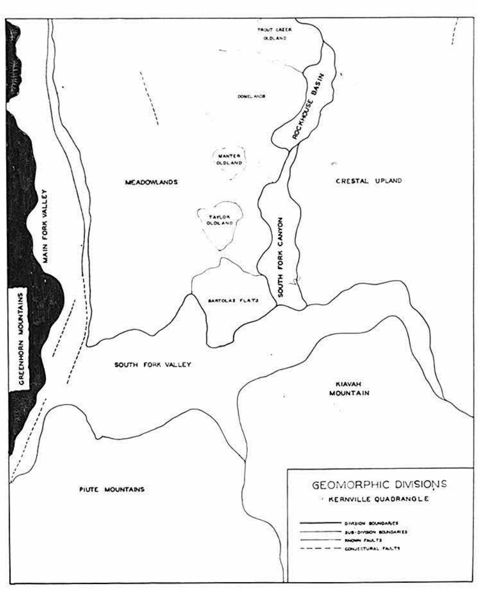
Introduction.

The Sierra Nevada are, broadly viewed, a great geomorphic province of homogeneous form. Their simplicity was early recognized by Le Conte (1889, p. 261) when he showed them to be a great tilted fault block, in which he recognized complications that have since been much investigated. The southern Sierra, although simulating this simplicity, is not truly a tilted block, but, as has been pointed out by Miller (1931, p. 333), is a horst-block of rather simple form, without westward tilt.

The geomorphic investigations conducted by the writer have led to subdivision, description, and interpretation of a number of geomorphic provinces within the region. Although investigated in detail only within the northern Kernville quadrangle, these provinces have been traced north and south for sufficient distance so that interpretations of the geomorphology apply to most of the southern Sierra.

The Greenhorn Mountains.

Introduction.



From the San Joaquin valley on the west rising through a series of foothill steps, occur a group of north-south sub-parallel ridges that are probably separated by faults. (Hake, 1928; Miller, 1931.) These ridges, from twenty to forty miles in length, become

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Location, Greenhorn Mountains. (Figure 2) progressively higher toward the east. The easternmost of these ridges is called the Greenhorn mountains.

Character of the Range.

The fault block character of this range was suggested originally by Lawson (1906, p. 399), and later by Hake (1928, p. 1028) and Miller (1931, p. 335). Hake says:

> "The southward continuation of this scarp [a scarp previously described in the Kaweah area] is the steep western flank of Greenhorn Mountain, which rises precipitously some 2,000 to 4,000 feet above the alluviated valley of Poso Creek, which parallels the base of the mountain. The general configuration of this slope suggests that it is an eroded fault-scarp, and the spurs which lie between the young streams now dissecting it are interrupted by steplike declivities that stand approximately in line, suggesting distributed faulting."

The general elevation of the Greenhorn mountains is about 8000 feet, with minimum elevations of 5000 feet in the southern part. Dissection of the east slope of the range decreases the boldness of the mountain block, which gives the observer the idea that this block is of subordinate importance as compared to adjacent uplands.

To the south, the Greenhorn mountains merge more or less with the lower heterogeneously grouped ridges and valleys of the Tehachepi mountains. To the north, they are absorbed by the more complex areas west of the Great Western divide.

Drainage.

The western drainage of the Greenhorn mountains is into the San Joaquin valley; the eastward drainage into the Main Fork of the Kern river.

Geomorphically important east flowing streams draining the Greenhorn block are, from south to north, in the area of detailed study, Bull Run, Tobias, South, and Dry creeks. All have steep uniform profiles, are of considerable length, but merge into the Main Fork valley with strikingly different topography and structure.

Bull Run creek, the longest tributary, enters the Kern five miles north of Kernville. It is a permanent stream, of steep gradient, entering the Kern at accordance; it flows from the range in a valley which rapidly widens toward the point of confluence with the master stream. A large alluvial fan, deposited by the stream in a previous stage, is trenched near the point of juncture.

Tobias creek has a shorter, steeper course than Bull Run. It enters the Kern accordantly twelve miles above Bull Run creek. It has a uniform profile from head to mouth, flowing in a distinct V-shaped canyon. Tobias creek, similar to Bull Run, has trenched an alluvial fan at its junction with the Kern.

Four miles north of Tobias creek enters South creek, which flows in a sharp V-shaped canyon from the crestal backland in a northward and then eastward course. Its gradient is in distinct contrast to that of other tributaries of the Kern. It is steep in places, sluggish in others where temporary base levels have been established. Its confluence with the Kern is accordant.

One mile north of South creek enters Dry creek. Its course is similar to that of South creek, except that its upper reaches cross upland meadows of an oldland surface; these meadows are typical of the region from this point northward.

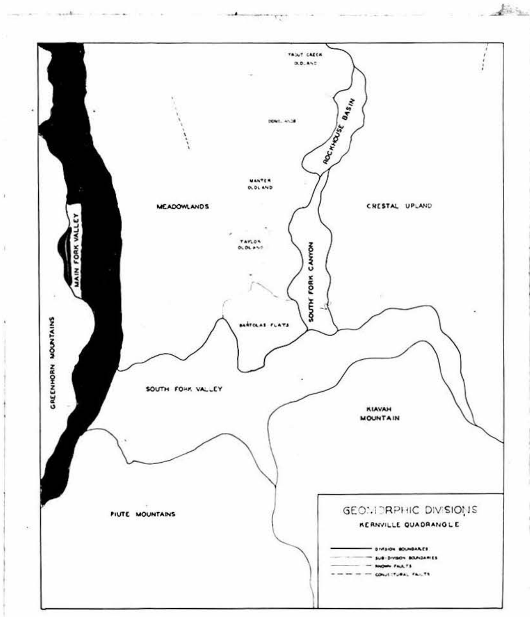
Summary.

The Greenhorn mountains are a mass of granitic rocks, undergoing rapid stream erosion, in late youth to early maturity in a second cycle of erosion. The remnants of the first cycle are preserved in the flat-topped summits of the highly dissected block.

The Main Fork Valley.

Extent, Size, and Character.

The valley or canyon occupied by the Kern river extends in a north and south direction through the central and southern Sierra for more than one hundred miles. Remnants of an earlier cycle valley are preserved along most of its length. The area of detailed study includes about twenty-five miles of the canyon. Of the course of the Kern within the Main Fork valley, Olmsted (1901, p. 14), in a reconnaissance paper on the Kern river basin says:



Location, Main Fork Valley.
(Figure 3)

> "The length of Kern River from King[s] River summit, on its main fork, to the mouth of the canyon above Bakersfield is 118 miles. The channel is in granite [and metamorphic rocks], and, with the exception of a few drops in the lower reaches of the stream, the grades are fairly uniform. In the 62 miles above Kernville the stream falls 5,600 feet, and in the 48 miles below Kernville it falls about 2,100 feet."

The width of the Main Fork valley varies from a few hundred feet to more than a mile. As would be expected, the wider areas are opposite

Figure 4. Gorge of Main Fork of Kern, south of Dry creek, looking south.

Figure 5. Fault-line scarp along east side of median ridge within Kern canyon, near Salmon creek, looking south.

the mouthes of the larger tributaries. North and south of Kernville, a temporary graded reach has been established above the junction of the South Fork of the Kern, where aggradation has occurred. Here the canyon has its maximum width.

The canyon in which the Kern river runs does not comprise the entire width of the Main Fork valley. Within the valley, east of the river itself, and on the east side only, lies a median ridge which rises as high as 6500 feet, fully 3000 feet above the average elevation of the canyon floor. This median ridge is separated from the true boundary of the Main Fork valley province by a line of canyons, cut by minor tributaries of the Kern river. (Figure 7.) The line of canyons, with intervening east-west divides, runs the entire length of the east side of the valley from Kernville to the confluence with the Little Kern river about thirty-five miles to the north. The eastern wall of the line of canyons rises as a bold west-facing front, marking the western boundary of the Meadowlands province.

Characteristics of the River Course.

At the point at which the river enters the Kernville quadrangle, it is running in a rock-cut, rock-floored gorge, fully 400 feet deep, in massive granodiorite. Less than one-quarter mile from the boundary of the quadrangle, the first tributary stream, Dry creek, joins the Kern from the west. The path of the Kern above Dry creek is roughly north-northeast to south-southwest; at Dry creek the river curves sharply about eighty degrees, flows south-southeast for about one-eighth mile, and then curves sharply south-southwest. (See topographic map.) Following this general direction for about one and one-half miles, the river crosses the contact between the granitic rocks and their facies, and the Kernville series (Miller, 1931, p. 335) of complex metamorphic rocks. After crossing the contact, South creek enters from the Greenhorn mountains. At the South creek junction, the Kern turns N45°W-S45°E, (parallel to the strike of the Kernville series) and, following this direction for a very short distance, changes to an east-west course, even trending somewhat northeast; in the course of less than one-half mile, it again flows north-south until it reaches Brush creek, one of the major affluents of the Kern, and one of the major streams draining the Meadowlands province.

From the Brush creek confluence, the river follows a meandering course, first parallel to the structure of the Kernville series, then across it, finally emerging again into the granitic terrane where Tobias creek joins the Kern from the Greenhorn mountains.

From Tobias creek southward to Kernville, all tributary streams from the west, and some from the east, show the same general characteristics. A general statement regarding the western tributaries was made by Lawson (1906, p. 403). He says:

> "Pursuing now our observations up [from Kernville northward; the description above is from north to south] the Kern River above Kernville, we find the stream flowing in a profound but remarkably straight canyon. The general trend of the canyon is much more nearly a straight line than is the course of the stream which flows in it. On the west side of the canyon the crest of the mountains [Greenhorn] is in general about ten miles back from the river. Numerous tributary streams enter from this side and all of them, as far as Tobias Creek, twenty miles above Kernville, have built up huge alluvial cones which indicate a marked lack of accordance between the action of these affluents and the main stream, which is itself running on bedrock and deepening its trench."

Four miles below Tobias creek, from the east, enters Salmon creek, the major tributary which emerges directly from the Meadowlands. This stream enters the river at accordance, but it is extremely oversteepened in gradient in the lower part of its course; it shows no evidence of alluvial fan accumulation at the point of confluence with the Kern.

Several miles south of Salmon creek, Bull Run creek joins the Kern from the west. Here the influence of the graded reach at the junction of the Main Fork and the South Fork of the Kern is apparent, and the Kern is a sluggish stream more or less braided, flowing on a large flood plain.

A generalization strikingly applicable to the drainage relations of the Main Fork province and the adjacent ones, is that, from the Greenhorn mountain side many small tributaries, closely spaced, enter the Kern, while from the Meadowlands province, widely spaced tributaries of considerable size enter. This is due to the median ridge which concentrates the streams entering from the eastern upland, diverting them along the line of saddles and canyons which is sub-parallel to the Kern.

The East Side of the Valley.

As pointed out by Lawson (1906, p. 504),

> "The geomorphic features of the east side of the Kern Canyon from the vicinity of Kernville to the mouth of the Little Kern are in remarkable contrast to those of the west side. In general the east side of the canyon is more precipitous than the west side, and it appears to be the edge of a high uneven plateau. [Called in this paper 'the Meadowlands'.] The streams are shorter and frequently fall in cascades over the steeper portions of the canyon wall in notches of no great depth. The Kern in the first twenty miles of the stretch under consideration is crowded to the east side of the canyon by the large alluvial cones on the west side and similar cones are only feebly developed in the east side.

These facts in themselves indicate a rather striking contrast in the geomorphic aspects of the two sides of the canyon, but the most notable feature of the east side and one which is entirely absent on the west side, is a series of high and prominent ridges and butte-like peaks which are arranged along the canyon side in an almost straight line. These ridges and buttes extend along the whole length of the canyon from near Kernville to the Little Kern. [About thirty-two miles.] They lie within the canyon and reach in general from about one-half to two-thirds the height of the canyon wall, and they are separated in each case from the main canyon wall by a defile or col which is generally several hundred feet lower than the summit of the ridge or butte. [The line of canyons and saddles referred to above.] Between these ridges or buttes flow transversely the affluents of the Kern from the notches in the main canyon wall. The entire series present the appearance of a continuous ridge, separated from the main canyon wall by an equally continuous narrow defile, which has been dissected by the affluents of the Kern which now pass through it." (Figures 6 and 7.)

One or two supplementary remarks are necessary to complete the picture. As the lateral tributaries of the Kern emerge from the eastern upland and flow down the edge of the valley wall, they are joined by lateral streams flowing along the defile. Many of these laterals do not flow exactly parallel to the defile, but at a slight angle to it. Thus the drainage is of crude trellis pattern.

Where streams cross the defile and the ridge west of it, they deposit alluvial materials behind the median ridge and in the defile in the form of large alluvial fans, which are extremely blunt at their western margins where they impinge upon the median ridge; they taper rapidly toward the escarpment at the east edge of the canyon. This detritus is thick at the base of the median ridge, and thin at the margin of the escarpment. The material is coarse, and unsorted. Fans showing this relationship are present along Brush creek and its northern lateral, named here

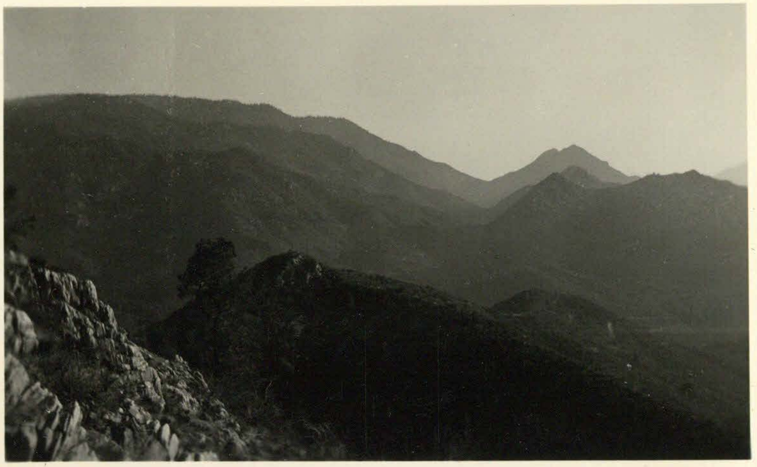


Figure 6. Looking south along Kern canyon fault-line valley with median ridge of Kern canyon on the west.

Figure 7. Looking south from the divide north of Salmon creek along the Kern canyon fault-line valley and median ridge in Kern canyon.

Breccia creek; along Brin and Packsaddle creeks to the south, and along Salmon creek, also along the next southward tributary from the east (called here Siphon creek) where the defile and median ridge are subordinate due to a decrease in height of the median ridge. This decrease in height of the ridge causes Siphon creek to extend its fan into the Main canyon and Kern channel, thus leaving no differentiation of defile fan and river fan. Further south, Cannell, and to a lesser extent Cowell creek, shows the same features.

Thus, it may readily be seen that the valley of the Kern, at least in the area of detailed study, shows physiographic features that well justify its assignment to a separate geomorphic province.

The Origin of the Kern River and Its Canyon.

Examination of any map of the Sierra Nevada brings out at once the striking discordance of the rivers of the southern Sierra Nevada, especially the Kern, with those of the central and northern part of the range. This discordance was commented upon by Drake (1897, p. 570). He says:

> "The Kern River is the first to break the general westward course and flow south for most of its length before turning toward the California Valley."

This discordance may have been developed in one of two stages in the geomorphic cycle. The southern trend of the stream lines may have been established in the Nevadian[1] range, and upon rejuvenation by faulting to initiate the present form, the Kern, and other streams, may have maintained their courses; in other words, an inherited drainage. Or, the drainage pattern may have been established in the early stages of deformation which produced the Sierra, either by a southward tilt, a structural

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1 Nevadian Mountains. The folded Jurassic antecedent of the present Sierra Nevada.

weakness, or a combination of these. Yet a third hypothesis might involve a combination of factors produced in both cycles.

The evidence available is meager. The writer agrees with Drake (1897, p. 570), and believes that the drainage of the Kern basin was well established, possibly along the Kern canyon fault, with drainage basins well defined, before the inauguration of the present range. This would indicate inheritance of form from the Nevadian cycle, in which a southern course of the Kern was well established. This hypothesis is strictly tenable according to the views of Lawson (1904, p. 363), who points out that the eastern part of the Nevadian range was reduced to a surface of moderate relief, not a peneplain, which had greater relief in the south than in the north.

The concept of long established southward drainage is supported by (1) the benchlands of an earlier cycle preserved high up on the Kern canyon margins, (2) the fault-line scarp, to the east of the river, which was exhumed by the river after planation of the drainage area, and (3) the seemingly ancient date of the Kern canyon fault (see p. 78).

Southward tilting during rejuvenation at the time of initial deformation of the Sierra Nevada is not essential in maintaining the southward flow of the Kern, if the southward drainage was established in the Nevadian cycle. However, the amount of downcutting accomplished by the Kern in the period of time since the inauguration of the Sierran cycle, strongly suggests impetus added by a southward tilt at the time of the initial Sierra deformation. This idea is supported by the observations of Miller (1931, p. 334), when he states that

> "Across the southern part of the region . . .
> the higher altitudes . . . [indicate] . . . .
> a distinct down-tilt of the plateau surface.

[The Meadowlands and Greenhorn provinces.] The southerly courses of the two main forks of the Kern River . . . . are believed by the writer to be direct responses to this southerly tilt of the old upraised surface."

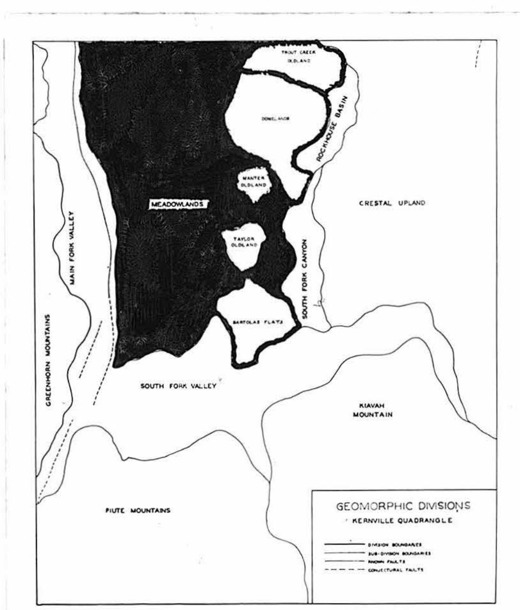
Any hypothesis which attempts to integrate the history of the geomorphic features of this region must adequately account for the discordant drainage of the Kern.

The Meadowlands.

Introduction.

The Meadowlands province is the largest physiographic subdivision in the area. It contains the highest elevations, and the greatest diversity of physiographic form. Described under this province are three sub-provinces: the Domelands, the Bartolas flats, and the Oldlands. Probably the features of greatest interest within the province are the extensive system of meadows found on the upland surface.

Boundaries.



The accompanying figure indicates the limits of the Meadowlands province. Its northern limit has not been determined. It is certain that it extends at least twenty-five miles northward; in fact, it appears to be traceable into the region of glaciation.

Location and boundaries, Meadowlands province.
(Figure 8)

Drainage.

The Meadowlands are drained by a large number of streams, all eventually contributing to the flow of the Main Fork of the Kern. The westward flowing streams have short, steep courses, with pronounced gradient breaks where they enter the Kern canyon. From north to south the most important watercourses are Brush, Salmon, Cannell, and Cowell creeks. The eastward flowing streams have longer, less steep courses. They are far more numerous, and seem to drain basins which are remnants of an old high valley system. Chief among these are, from north to south, Trout and Little Trout, Fish, Manter, Taylor, Bartolas, and Fay creeks.

The accompanying group of photographs indicate the characteristics of the region drained by these streams.

The Meadows.

Introduction.

The dominant feature of the Meadowlands province is the presence of more than twenty distinct meadows, varying in size from a fraction of a square mile to as much as four square miles. These meadows are of sufficient importance in the geomorphic history to warrant detailed descriptions of some of them. The meadows are not confined to the Kernville area, but are also present in the Olancha quadrangle to the north (plate XVI), where the meadows are generally much larger.

Descriptions.

Big meadow, in the central part of the Meadowlands province, is probably the best representative of the larger meadows. (Figure 9.) It lies on the headwaters of Salmon creek. With a surface area in excess of

Plate I.

Round meadow, on headwaters of Brush creek, showing grassy levels, typical of upland meadows of Meadowlands province.

Figure 9. Gorge of Salmon creek, with Big meadow in the foreground, looking west. The nature of the rock-bound gorge of the meadow is shown.

Figure 10. Upper Cherry meadows, typical example of a headwater meadow. Head of Brush creek drainage.

four square miles, it is covered with luxuriant grass. The meadow is drained by Salmon creek which meanders over it in no well-defined channel, turning the meadow into a marsh whenever a large volume of water is in the stream. The meadow margins are typically irregular, with long entrants of meadow encroaching into the wooded margins. Between these are timbered salients. In almost every case, and especially in Big meadow, the outlet of the stream draining the meadow is rock-bound. Whenever this is true, the margin of the meadow adjacent to the outlet is relatively straight. At these outlets, large springs generally emerge to augment the stream flow.

Some streams have trenched their meadows, while others flow over them without channel, as in the case of Big meadow. When trenching occurs, it is generally to depths varying from two to twenty-five feet.

Where streams have trenched their meadows, it is sometimes possible to see the character of the meadow fill. In some cases, the bedrock is exposed in the stream trench; in others alternate layers of fine sands and fine gravels, with organic and mud layers are seen. Where the bedrock is exposed, it is generally true that the soil cover is thin, and has the approximate composition of the bedrock itself, suggesting origin in situ. Often on the meadows, away from the streams (especially in Long meadow) one finds projections of what is inferred to be bedrock sticking through the soils. In such cases the soil cover may be considered to be dominantly residual; where no bedrock projections are seen, a reasonable inference seems to be that most, if not all, of the material in the meadow is transported. These inferences are justified by the frequency with which one sees known bedrock in meadows without stratified fill, as compared to those where fill is prominent, in which no bedrock projections are seen.

The small meadows are best developed on the headwaters of streams which emerge from springs; they are best described as muddy marshes, which have small streams in them formed by water oozing up from springs. These meadows are very small, sometimes scarcely more than spring terraces; they vary to some that are grasslands 200 to 300 yards long and fifty yards across. These meadows never have rock-bound outlets; the streams draining them coalesce into a channel, develop normal gradient, and join master tributaries lower down. Sirretta meadows is a good example of this type. Other examples are Round and Little Round meadows, the Cherry meadow system, and Woodpecker meadows. (Plate I, and figure 10.)

An interesting sidelight on the trenching of these meadows is the program of soil and meadow conservation instituted recently by the Federal government. In the area, brush and small earth fill dams have been constructed at closely spaced intervals within the meadows in an effort to cause deposition, and to prevent their destruction by the streams.

Types of Meadows.

The meadows of the province may be divided into two types, the first being far more important. The large meadows are those of the "sub-summit meadows" class, to which most belong. The second are called the "headwater meadows"; they are found dominantly on the headwaters of the streams.

The Sub-summit Meadows.

Characteristics.

The sub-summit meadows are characterized by (1) their size, varying from one-quarter to two or three square miles (2) their position along the course of the streams, seldom being on the headwaters, except where large springs emerge in meadows close to the summit of the province (3) the occurrence of more than one meadow at successively lower levels along the course of a single stream (4) the presence of a gravel series in each meadow, of varying thickness, and kind (5) the almost uniform trenching of all meadows (6) the relatively lower elevation of the meadow surface giving a basin-like effect (e.g., Big meadow, plate II and figure 9) (7) the rock-bound outlets of all meadows, and (8) the fact that they are closed basins except for the rock-bound outlet.

Problems in Origin.

It can be seen at once that the explanation of the origin of the sub-summit type of meadow must account for many varied conditions. The greatest problem lies in accounting for enclosed basins, of slight sedimentary fill, and for the rock-bound outlets. It seems almost necessary that the one-time presence of closed basins must be postulated to account for these unique forms.

Consideration of Hypotheses.

Upon critical analysis of the problems to be explained, it seems that only two hypotheses (1) glaciation and (2) deformation, could possibly produce closed basins of the type found in the region. The evidence is meager. The writer favors the glacial hypothesis as most nearly satisfying the facts, although it may well be that it is incorrect. Further studies may bring new information to light, however. The writer hopes to pursue work in the region for a number of years to come, in an effort to throw new light on the problem.

Deformational Hypothesis.

First, let us briefly consider the hypothesis involving deformation. It has been of interest to obtain the reactions of others upon brief visits to the area. Several have favored the deformational hypothesis; it is admitted that it would be the simpler of the two. If, by faulting, closed basins were formed, the evidence would be quickly removed and such features might result. The writer is convinced, however, that in the numerous cases of meadow development in this province and others in adjacent regions, that some positive evidence of faulting should be found. Considering the deformational hypothesis from the point of view of warping, it would seemingly be a coincidence that so many local warps of small extent and non-regional character could have formed. One finds streams draining in all directions from the meadows; in such cases warping would have to take place across each stream course in order to enclose the basin. Thus, axes of warping would "box the compass". However, the writer prefers an hypothesis for which, he believes, there is more evidence, and to which fewer objections may be raised.

Similar Meadows of Other Areas.

Areas of what appear to be. similar meadows occur in other places that have been geomorphically studied in Southern California and elsewhere. In explanation of them writers have offered various hypotheses.

In a paper by Lawson (1906, 2), several alluviated valleys in the Tehachepi mountain region were discussed which seem to have some features in common with those of the Kernville area. These are, it is suggested, due to deformation by faulting, which has caused alluviation. The evidence in all cases is physiographic, and not convincing. Buwalda (1915;

1920) has, however, added evidence which places the deformational hypothesis for these valleys in a more favorable light.

Baker (1911), in describing the geomorphic features in Bear and other valleys in the San Bernardino mountains suggests that these meadows and lakelands have been formed by solution of the limestone areas which he says underly much of the meadow areas. These meadows are strikingly similar to those of the area under consideration.

Vaughan (1922), in discussing the same features of the San Bernardino mountains, has shown that Baker's contention cannot be upheld, because the meadows of the San Bernardino range are not underlain by soluble rocks. He, instead, proposes the theory that they are preserved remnants of a second cycle of erosion which produced wide valleys.

Meadows of the Olancha Quadrangle: The Deformational Hypothesis.

Knopf (1918, p. 84), in describing geomorphic features of the Olancha quadrangle in the vicinity of Templeton meadows, offers the following to explain a meadow, in a closely associated area, known to be of the same type as the ones of the Kernville area. He says:

> "Many of the broad grassy meadows in the summit region south of the southern limit of glaciation are . . . . drained by the South Fork of Kern River, a stream that displays certain peculiarities demanding explanation. At Templeton Meadows South Fork meanders upon the floor of a broad valley . . . . Farther southward it enters a deep gorge several miles long, from which it emerges upon the broad Monachee Meadows . . . . Farther southeast it enters a meandering vertical-walled canyon intrenched 200 to 500 feet in the floor of an old valley . . . . which lies 1500 feet below the crest line south of Haiwee Pass . . . . Farther south the stream again emerges upon broad meadows. The only reasonable explanation for this singular behavior of South Fork would seem to be that

> the canyons represent downcutting across zones of upwarp whose axes lie athwart the stream course. The recognition that deformation of this kind has accompanied the uplift of this part of the Sierra Nevada introduces a new element of complexity in the decipherment of the physiographic history."

The writer agrees that such features are suggestive of deformation. It seems that Knopf's hypothesis is weakened by the fact that no other evidence of extensive warping has been uncovered in detailed studies of adjacent areas. It scarcely seems necessary to point out that deformation, if such is the cause of the meadows, would be along no uniform axes, as meadows, having rock-bound outlets, drain in all directions. This seems to the writer to be an insurmountable obstacle in the way of a deformational hypothesis.

Discussion of the Glacial Hypothesis.

General Statement.

It has been suggested that glaciation was the cause of the closed, sediment-filled basins, which today are meadows. It is probable, at a very early time in the glacial history of the Sierra, that isolated "nivation" glaciers filled matureland areas on the summit of the Meadowlands block, and scoured and deepened valley heads sufficiently so that when the glaciers melted, small lakes were left into which the sediments of the present meadows were deposited. This contention is strengthened by the relatively small size of the basin areas, and their isolation. This hypothesis is, of course, in direct contradiction to the opinion of Dr. Matthes[1], who believes that the lower limit of glaciation is in the near neighborhood of 10,000 feet, and that 8000 foot levels farther south than the now recognized

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1 Personal communication.

limit of glaciation in the Sierra, probably did not have glaciers even in an early stage.

The findings of some other workers favor glaciation at elevations nearly as low as those of the Meadowlands block in closely similar regions. For instance, Blackwelder (1931) points out that evidence for the earliest (McGee) glacial stage in the central Sierra is meager, chiefly in the form of old bouldery moraines, and that (p. 906)

> ". . . . the land surface of that age has been so largely consumed . . . . that there can be little hope of finding many or large remnants of this drift."

In the San Bernardino mountains at elevations of about 13,000 feet, Fairbanks and Carey (1910), and later Vaughan (1922, p. 335) have shown conclusively that glacial features are present.

In the San Gabriel mountains, Miller (1926) has shown that certain forms on the summits of the range are suggestive of glaciation, and explains them thereby.

It seems logical, if these glacial occurrences in the mountains of Southern California are bona fide, that glaciation in an early stage (Blackwelder, 1931, p. 881) in the Sierra, at levels of from 7500 to 8000 feet, would not be improbable.

Evidence for the Glacial Hypothesis.

The Stages of Meadow Development in the Area.

There are recognizable in the region four distinct stages in the evolution of the meadows. It is not considered that these are the only stages passed through in their evolutionary history, but that they represent the latest stages since glaciation.

<u>The Lake Stage</u>: Two meadow areas are indicated on the map as intermittent lakes. [Lower and Upper lakes in the Taylor creek drainage.] A first distinct stage is here represented. It is inferred that these lakes are remnants of the glacial lakes which have been drained by the down-cutting of their outlets, and by filling with sediment. In general, both Upper and Lower lakes are filled with marsh grass, and are nothing more than stagnant pools in which the deer wallow in search of food. They are not fed by underground springs, but result from the ponding of rain water and melting snow. No evidence of dams of any kind are present in any of the meadows. Landsliding, morainal accumulations, etc., could not account for them.

That these are representatives of the earliest meadow stage is indicated by: (1) the fact that the lake areas, when dry, have all the characteristics of the present day meadows, (2) the depth of the lakes is but five to fifteen feet below the present outlets, which are rock-bound, and which are being rapidly reduced by erosion, (3) the position of the lakes along the stream course, similar to meadow positions on other streams.

<u>The Meadow Stage</u>: The meadow stage is represented by accordance of the meadow level with the outlet, and complete filling of the bottom lands. In this stage, the entire surface of the meadow is grasslands. Most meadows of the area are now at the close of this stage. Slight trenching of the meadow by the stream indicates the transitional approach to the next stage.

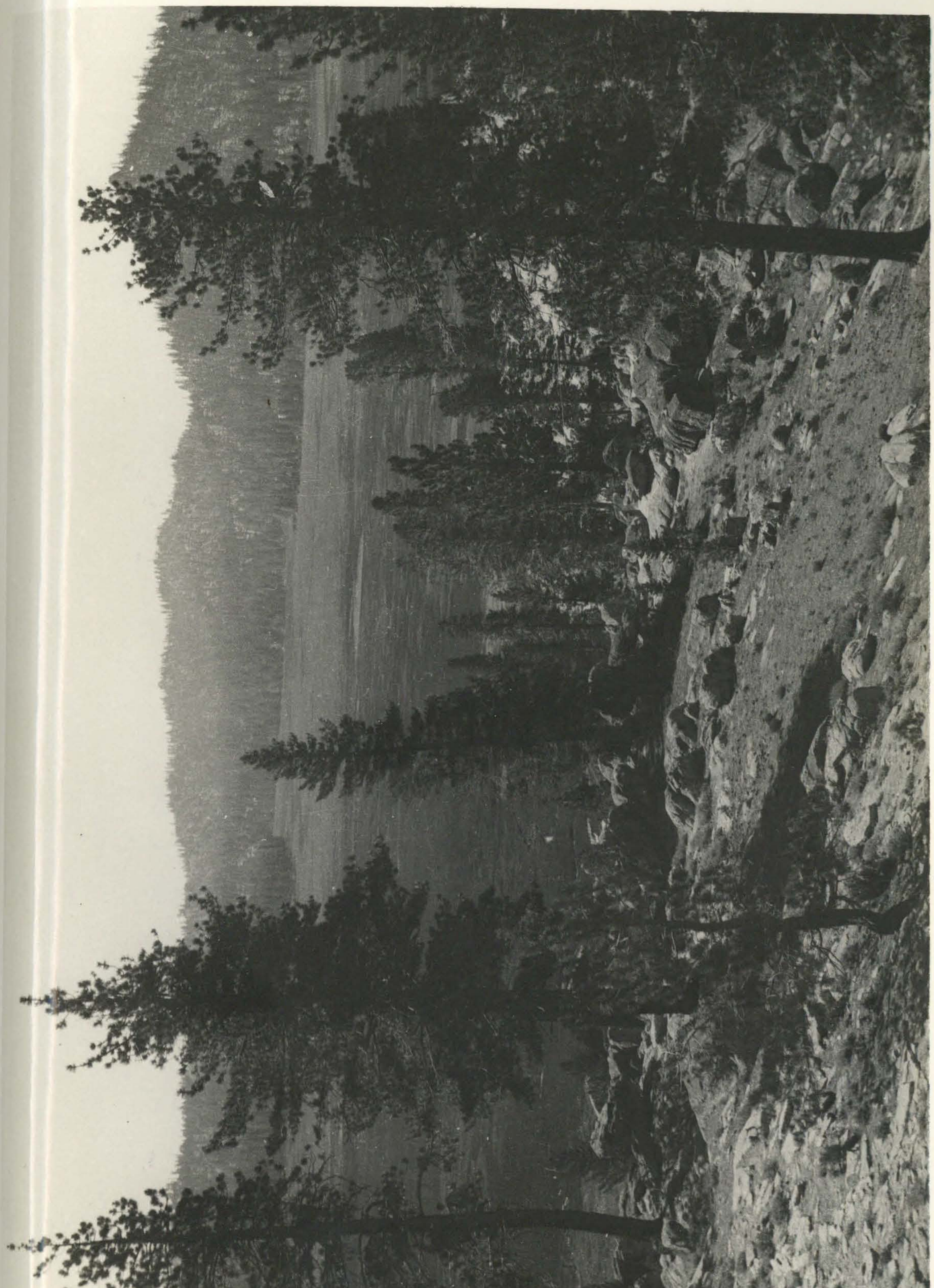
<u>The Trenching Stage</u>: As the outlets of the meadows are cut down, streams draining them tend to work headward and remove the sediments deposited in the basins. Where this has taken place, the sediments are well exposed. The best example of this stage is Smith meadow, a small, but typical meadow in the dissected stage.

Figure 11. Upper lake, head of Taylor meadows, looking west.

Figure 12. Lower lake, head of Taylor meadows, looking east.

Plate II.

Looking south across Big meadow. This is the largest meadow of the Kernville area, and is an excellent example of the meadow stage of meadowland development.



Destruction: A fourth possible stage may be inferred. As trenching progresses, complete destruction takes place by removal of all detritus, and erasure of the meadow. This has undoubtedly taken place; the evidence would, however, soon be removed. It is suggested that such a stage may be represented by some small, high, gravel covered levels, in the Taylor drainage, that are now almost entirely destroyed.

Another method of destruction of the sub-summit meadow occurs. Alluvial fans, accumulating as a result of a large storm or cloudburst often cover the upper end of the meadows, and, gradually encroaching upon the meadow areas, destroy them.

The Meadow Sediments.

The trenched stage in the meadows is not everywhere developed. In two cases vertical sections of the sediments were obtained. In Long meadow the thickness of sediment is less than five feet, lying on a granitic bedrock. Granitic sands and fine black organic silts not more than three inches thick are intercalated with one another in no particular order. Much organic material, highly oxidized, is found in the silt layers.

In Smith meadow, a section above the bedrock is as follows: (See plate IV.)

Detailed Section of Deposits in Lower Smith Meadow.

(Top) Talus material.	Conglomerate, sandstone and arkose. Sub-angular fragments, with few oxidized roots.	3 feet.
Granitic conglomerate.	Boulders in arkosic material from ten inches in diameter down, some rounded, in various stages of decomposition.	8 inches.

Plate III.

Looking southeast across upper Smith meadow, with 7705 dome in background. Notice how alluvial materials are encroaching upon the meadow surface. Such gravel deposits are probably followed by a new grass growth, which, again, is erased by gravel encroachment.

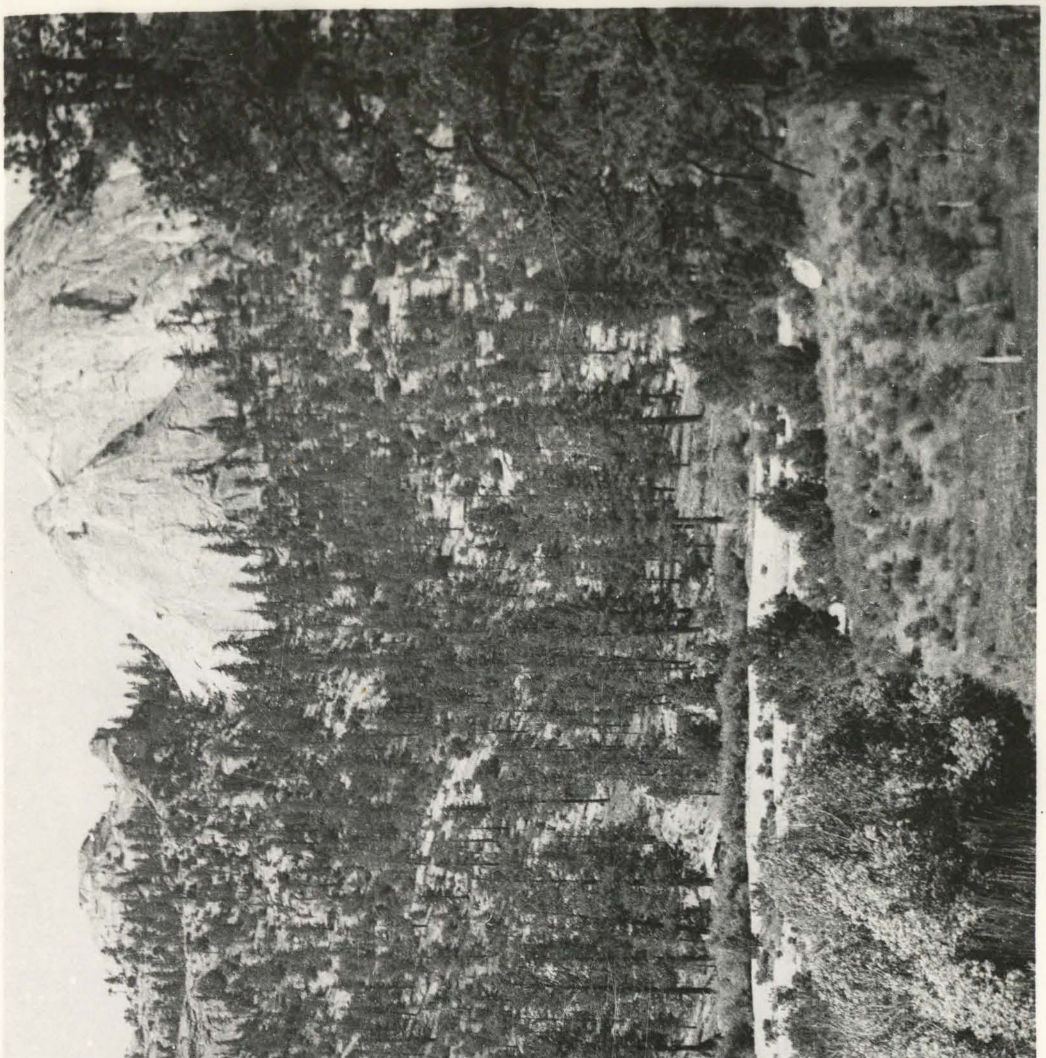
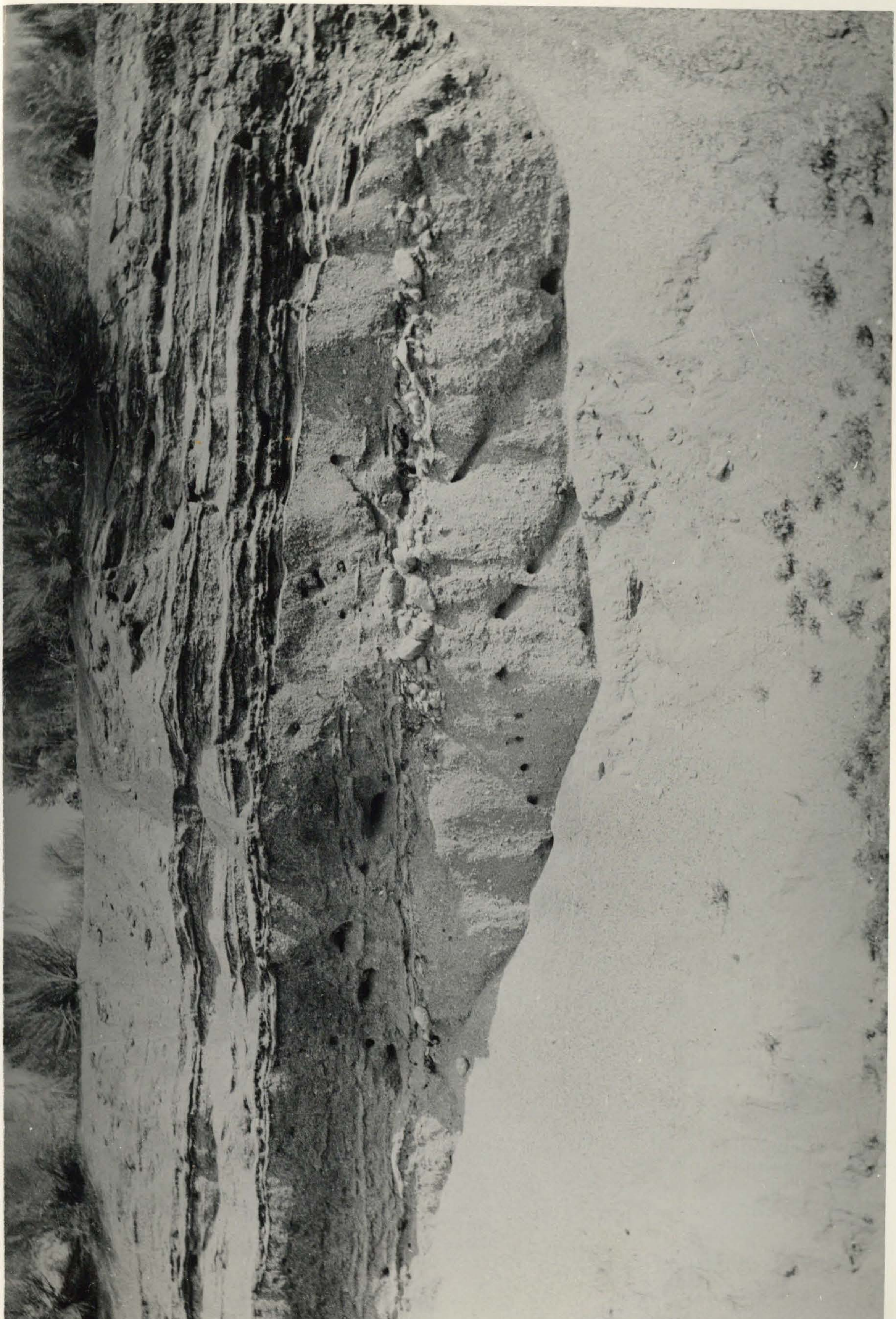


Plate IV.

Gravels in lower Smith meadow. Notice coarse conglomeratic sands, and fine organic mud layers. Visible only in trenched stage of meadow destruction.



Swamp silt.	Black, fine silt, micaceous, with many roots, highly oxidized.	4 inches.
Swamp gravelly sand and grit.	Small pebbles about one inch in diameter. Interstratified with swamp silt. Black.	2 feet.
Silts and Sands.	Finely stratified, and slightly cross-bedded silts and sands with much oxidized organic matter, including some peat.	6 feet.
		12 feet.

It seems difficult to account for such sediment sequences and sorting without postulating shallow lakes as basins of accumulation. Other meadows show similar sorting and composition of sediments.

The elevations of all meadows are from fifty to seventy-five feet below the present summit surface of the Meadowlands province. The meadows are drained by streams flowing through rock-bound gorges with depths equal to the difference between summit surfaces and meadow surfaces. To account, then, for closed basins below the general summit level, with outlets now at the basin level, seems to require a standing body of water, in which sediment would be deposited and out of which streams would spill, rapidly cutting down the outlet and draining the lake. If such a condition did exist, it would produce features much like the present meadows. Continued cutting down of the outlet would produce trenching of the meadow sediment.

Evidence in favor of such an hypothesis is: (1) the character of the sediment in the meadows; such fine-grained materials, well sorted, would rarely be deposited under other conditions, (2) the fine almost paper-thin stratification, (3) the depression of the meadows below the summit surface remnants, (4) the small thickness of sediment found in most meadows; lakes being ephemeral features, would probably be destroyed before very great thicknesses of sediment could be deposited by waters from melting "nivation" glaciers, and (5) the presence of lake remnants in the region at the present time indicates the presence of larger lakes at an earlier time.

The sedimentary sequences of the meadows support the hypothesis of glacial origin. The surface on which the lake basins were formed was a late matureland, in the southern Sierra. As the glacial period began, valley heads of the matureland were filled with snow. Continued predominance of accumulation over melting eventually produced small glaciers, probably of granular ice, whose movement scoured and appreciably deepened the valleys near their heads. After retreat of the ice, lakes filled depressions along valley courses. Subsequently, the lakes were destroyed, either by cutting down of the outlet, by sedimentation, or by both processes.

Other Evidence of Glaciation in the Region.

In the central drainage area of Trout creek, boulder fields, lying on fresh granite, are perched in precarious places along the stream. The accompanying figure shows some of them. Their origin as erratics is suggested.

Summary.

It is believed that the glacial theory may be more nearly applied to the satisfaction of the facts than any other theory, to account for the presence of the meadows in the Meadowlands province. The glacial theory is supported by the following evidence: (1) the presence of lake stages of meadow development, (2) the character of the sediments in the meadows, and (3) the presence of probable erratics. It is hoped that future work will produce evidence to establish or reject this hypothesis.

Plate V.

Granitic slopes of Trout creek gorge, showing residual boulders which simulate erratics. Notice character of dome slopes. Looking northwest.

The Headwater Meadows.

A subordinate type of meadow occurs on the headwaters of some streams, especially those that have their source in springs. These are grassy patches, oftimes less than 100 yards on a side, many of them due to the coalescence of terraces formed by grass which prevents erosion of the material by the stream. It may also be that silt and salts are deposited by the springs; the shape of the deposits at the springs are often similar to those of hot spring terraces.

The Domelands Sub-province.

Within the Meadowlands lies a region of twenty square miles or more that lacks the typical meadows of the main province, but which is physiographically part of it. This area, called the Domelands, because of the extensive development of granitic domes, lies almost entirely in the Trout creek drainage area. The Domelands contain about ten large domes, all more than 7000 feet in elevation, the highest being 9529 feet. These domes are very prominent standing out impressively when viewed from the east. (Plate VII; plate XIII.)

The domes, although higher than the meadows themselves, probably escaped glaciation because favorable flatlands, where snow could accumulate, were not present, and because in the glacial hypothesis "nivation" glaciers would never become thick enough to override barren rocky summits. Dome-forming processes may have been progressing prior to glaciation, continued during it, and still going on. Matureland, inter-dome, and inter-divide flats would be favorable catchment areas for snow, in which glaciers would form.

Plate VI.

Headwater meadows on Cherry fork of Brush creek.
Notice skunk cabbage, and profuse floral growth.
Taken in August, 1935.

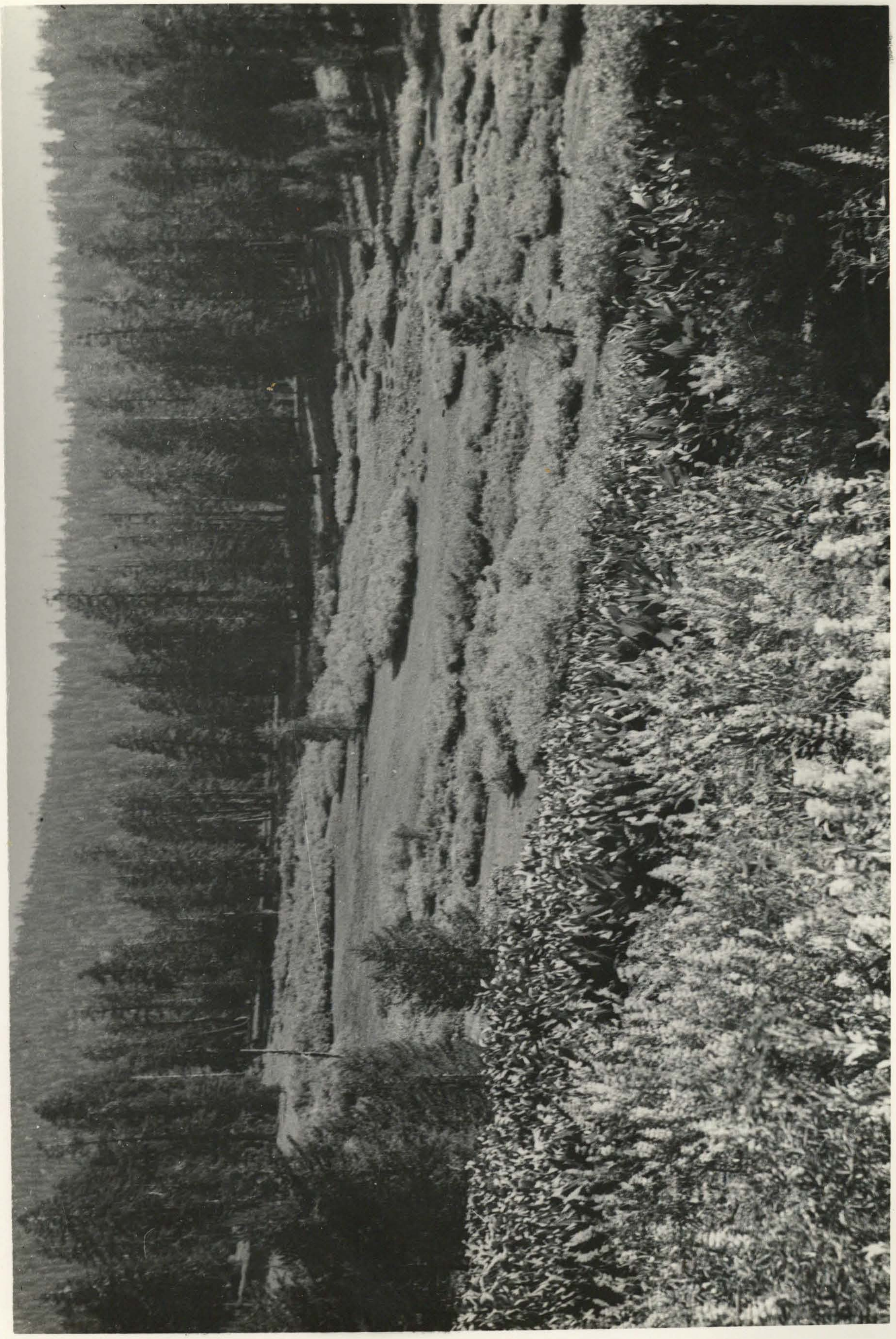


Plate VII.

Giant dome east of Smith meadow, with meadow in foreground. Note exposed sediments.

Origin of the Domelands.

Upon cursory examination of the Domelands it might easily be concluded that glacial action initiated their carving. Upon close examination one is convinced that they are due to chemical weathering in rocks of uniform composition along master joint systems of rectangular pattern, because (1) the rocks in which they are formed are confined exclusively to the granodiorite batholith and its phases; (2) the domes invariably occur where the joint systems are particularly well developed; (3) on the dome surfaces no fresh material is ever present; (4) the surfaces of the domes are deeply weathered, and often are surrounded by slopes and catchment areas of residual soils. Chemical weathering is dominantly active producing spheroidal weathering. Apparently exfoliation has played no part in the production of the domes.

The Bartolas Flats.

An area of ten square miles called Bartolas flats in the extreme southern part of the Meadowlands deserves special classification. Its average elevation is 7000 feet, from which it varies by not more than 200 feet, until the erosional escarpment of the margins is reached. In general, the Meadowlands province slopes gently from north to south, culminating on the south in the Bartolas flats sub-province, which flattens southward, much like the edge of a shovel, breaking the general southern slope of the province. This sub-province is a remnant of the once continuous summit oldland of the Meadowlands surface.

The Oldlands.

The oldlands comprise three areas within the Meadowlands province. The first of these embraces a sizeable area south of Bald mountain and the

Niggerhead, in the drainage of Fish and Trout creeks; the second, a much smaller but distinct area on the eastern side of Manter meadows (fig. 28); and the third, a small area in the drainage of Taylor creek, including Taylor and Rattlesnake meadows. These three areas have strikingly similar features and form. They are classed as sub-provinces of the Meadowlands.

Viewed from within, the oldlands have Meadowland summit characteristics. Not until they are seen from above, from one of the surrounding peaks or higher ridges, is it apparent that a surprisingly flat and monotonous topography has been dissected by numerous small streams, in dendritic pattern.

Origin of the Oldlands.

The oldlands are remnants of high-level valleys of an early stage of the Sierran cycle. Along the Kern valley similar oldlands have been described. The streams in whose drainage area the oldlands lie probably cut these surfaces during the deformational pause at the time when the Kern river benchlands were cut. This interpretation is reasonable because (1) the areas are small enough to have been cut by streams of size comparable to those now draining them (the oldlands are so bounded that it is certain they were never of greater extent than at present); (2) they lie at elevations along their streams below the summit oldland comparable to those along the main Kern; (3) the oldlands show an equal stage of stream dissection in the present cycle.

Summary.

The Meadowlands have an average elevation of 8000 feet, somewhat higher to the west, somewhat lower to the east; the surface is a highly

Figure 13. Looking south at the Trout creek oldland, in the middle foreground, with the Domelands in the middle distance.

Figure 14. Manter oldland, with White domes in the middle distance. Manter meadow in the center foreground. Looking northeast.

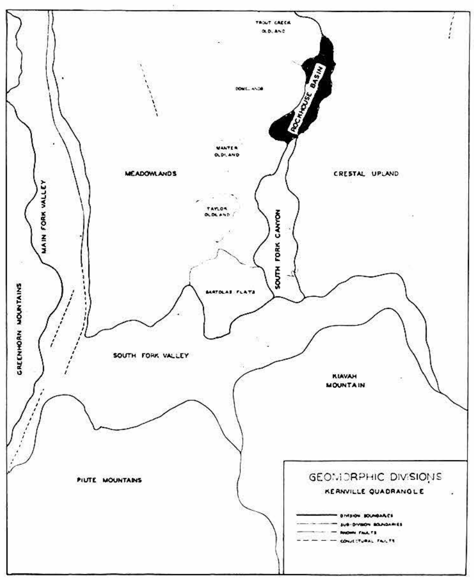
Plate VIII.

Looking northeast across Trout creek oldland, showing amount of dissection of oldland surface with residual boulders. Bald mountain in the background.

dissected plateau undergoing normal stream erosion, in a second or even third cycle of development, in which may be defined several physiographic sub-provinces. This province is by far the largest physiographic subdivision in the area, and the most important in the elucidation of the geomorphic history.

Rockhouse Basin.

Rockhouse basin is the name of a small meadow area along the middle course of the South Fork of the Kern, extending from above Fish creek junction to Rockhouse meadow, where the South Fork of the Kern enters South Fork canyon. In this area, the South Fork runs in an open valley, in a braided meandering course, mostly on bedrock, but with shoals of gravel and still, wide, pools. The gradient in the basin along the stream is less than 300 feet in ten miles.

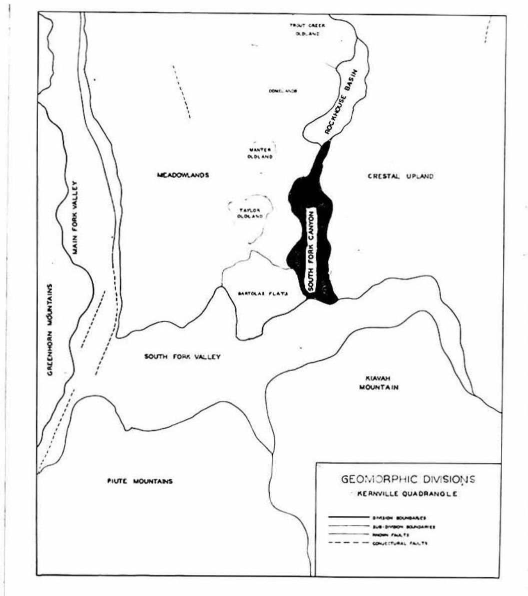


Location, Rockhouse Basin.
(Figure 15.)

The wisdom of placing this part of the area in a separate physiographic subdivision may be questioned, inasmuch as it coalesces with the Trout creek oldland. Because it is an interior lowland on the South Fork of the Kern, and because it is of less elevation than the Trout creek oldland, the Rockhouse basin is separately grouped.

South Fork Canyon.

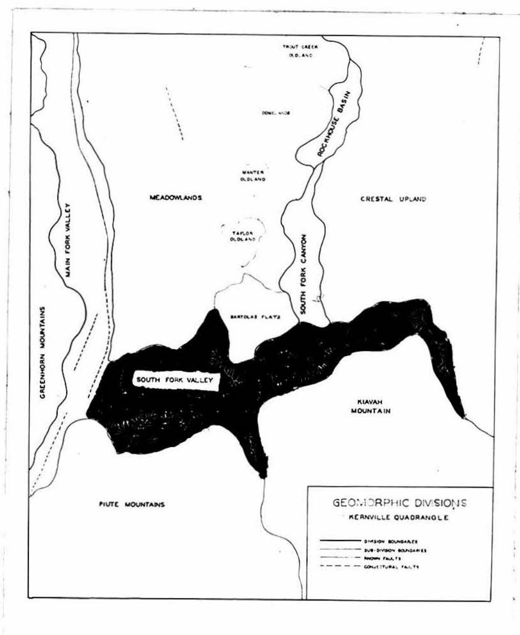
South Fork canyon needs but brief mention. The channel of the South Fork of the Kern, south of Rockhouse basin, is placed in this province. In reality, the gorge of the river is a great meandering breach separating the Meadowlands from the adjacent Crestal Upland to the east. The average gradient of the stream from Rockhouse meadow to the South Fork valley is 200 feet per mile. (See topographic map.) The tributaries joining the South Fork in the South Fork canyon province are from north to south: Manter, Taylor, Long, and Bartolas creeks.



Location, South Fork Canyon.
(Figure 16.)

South Fork Valley.

The South Fork valley is one of the most interesting provinces in the area. It offers a physiographic problem that has been studied in the past, and that has as yet not been satisfactorily explained. The South Fork valley is a wide east-west alluviated valley, from one to four miles wide, and nearly twenty miles long, which runs transverse to all regional



Location, South Fork Valley.
(Figure 17.)

structure and physiography. It is occupied by a small stream which wanders over the valley floor, and which is actively engaged in aggradation. The stream enters the valley at accordance from the tortuous South Fork canyon. The South Fork valley itself continues toward its head eastward onto the crest of the Sierra, with no drainage area to provide the necessary volume of water that it must have taken to provide tools and power enough to cut such a valley.

As was stated before, the South Fork of the Kern is a meandering stream, actively aggrading, and with many distributaries. (See topographic map.) Its descent, from the point of entrance from the South Fork canyon to its junction with the Main Fork of the Kern, is but 200 feet in twenty miles.

The Origin of the South Fork Valley.

The origin of the South Fork valley is one of the most puzzling problems of the entire area. No satisfactory theory has yet been discovered by the writer to account for this anomalous feature. Previous workers in the region have considered the cause of the alluviation. No one has, however, attempted an explanation of the westward course of the stream in a region of otherwise southern drainage.

It has already been shown that the drainage of the southern Sierra is prevalently north-south. The valley of the South Fork of the Kern is the one major exception; it has a course transverse to the regional drainage. It heads against the eastern crest of the Sierra, in a valley with a normal head, flows westward across the entire region, joining the Kern at Isabella.

The hypothesis which accounts for the anomalous drainage of the South Fork, must account for its transverse system and its alluviation.

Upon the inauguration of tilting of the Sierra block, a stream, of volume greater than at present, drained westward from the newly formed Sierran crest across the slowly rising block. As the vertical component of movement became greater, the South Fork valley developed as a canyon, with normal profile, tributary to the Kern, which was at that time flowing in a wide mature valley.

After the development of the canyon, aggradation caused filling of the valley almost to its head at the eastern edge of the Sierra. Aggradation may have been produced as follows: Shortly after movement on the Sierran fault uplifted the block, the San Joaquin marginal faults developed at the base of the Greenhorn mountains. This caused slight eastern tilting of the western Greenhorn block, west of the Kern canyon fault. This is known because the total amount of uplift on the western marginal faults is now equal to the displacement at a corresponding point due east on the Sierran fault, which indicates that the movement must have been that of tilting. This movement decreased the gradient of streams flowing toward the Kern river from both the eastern and the western sides and caused aggradation of valley floors. The result was the aggradation of the South Fork of the Kern, and the development of the alluvial cones along the Main Fork of the Kern above the point of junction with the South Fork, especially on the west side. Loss of gradient of the Main Kern also caused alluviation in the Main Kern valley.

Lawson (1906, 1, p. 402) has offered the suggestion that movement along the Kern canyon fault with downthrow to the east has caused the ponding of waters and the development of a lake in which delta material accumulated.

The acceptance or rejection of Lawson's hypothesis to account for the alluviation depends entirely upon factors that cannot be determined at the present time. The actual depth of alluvium at, or near, the point of confluence is not known. If the bedrock on which the alluvium lies, adjacent to the rock floored course of the combined Kerns, at the point of drainage behind the median ridge of Hot Springs valley, has a difference of elevation where the South Fork of the Kern enters, then faulting must account for the alluviation. No amount of tilting nor other factor can account for a difference in elevation of rock floors in the valley. It seems probable that this inference of displacement along a fault is reasonable, as all surface indications point to discordance of bedrock surfaces.

In this problem, a relatively local movement along a fault of short horizontal extent would produce the desired result as well as movement on the major Kern canyon fault. Such evidence of relatively recent movement that may have existed, would, of course, have been altered by erosion or buried by deposition. It is probable that action of this sort has contributed to the alluviation. The recent seismic activity reported in the vicinity of Kernville, is probably of local origin, and may be due to adjustments in the alluvium along subsidiary faults.

Miller (1931, p. 334) suggests that

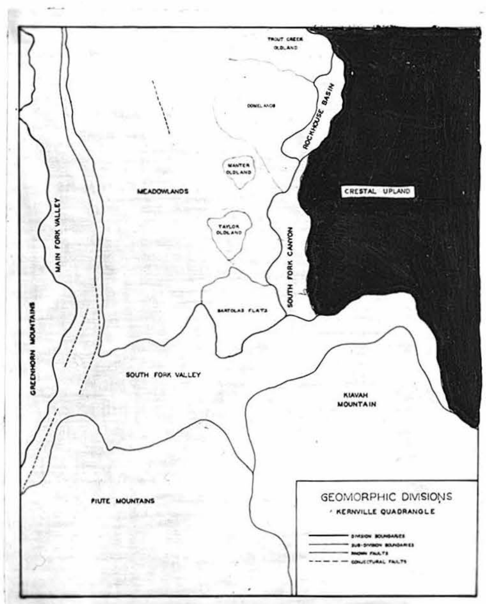
> ". . . . the main Kern River, which drained the once great system of glaciers of the Upper Kern Basin, may have been so loaded with sediment that, on reaching the wider valley with a lower gradient in the vicinity of Kernville and Isabella, it deposited enough material across the western end of South Fork Valley to pond the waters of South Fork temporarily."

This explanation may be valid if no bedrock discrepancy exists.

It must be admitted that the true explanation of the history of the South Fork valley still remains in doubt; the evidence for the complete picture is not available. It is possible that all three hypotheses presented above have contributed to the anomalous conditions.

Crestal Upland.

The Crestal Upland is the easternmost province in the area. It lies between the Sierran escarpment on the east, and merges with the Rockhouse basin-South Fork canyon on the west.



Location, Crestal Upland.
(Figure 18.)

Meadows.

Within the Crestal Upland are several large meadows that are strikingly similar to those of the Meadowlands province. It may be that they have a similar origin. Of these, Sacatar, Big Pine, Chimney, and Lamont meadows deserve special mention.

Sacatar meadow is, properly speaking, the alluviated valley of the Sacatar canyon drainage.

Big Pine meadow, on the head of Big Pine creek, is of small area, but of unusual interest because of the light it throws on the physiographic evolution of some of the trenches in meadows. Residents in the region informed the writer that the twelve foot trench in Big Pine meadow, which has its maximum depth at the western end of the meadow, decreasing in depth toward the head, was formed during a single cloudburst in the summer of 1928. Before this time the meadow was untrenched. It seems probable that much of the trenching to shallow depths seen in other meadows in the region may be attributed to local causes.

Chimney and Lamont meadows both lie in the drainage of Chimney creek, only three miles apart; they have such similar characteristics that they may be described together. Both are rather large, as much as two square miles in area; both have extended their influence to tributary canyons so that these have reacted to the temporary base level thus established, and are alluviated into their headwaters. Both meadows have been trenched and have rock-bound outlets, plunging into granitic gorges immediately upon leaving the meadow surface.

The trenching in both Chimney and Lamont meadows has exposed an interesting set of intercalated gravels and sands, with much carbonaceous material between. All beds contain decomposed plant remains, especially sticks and roots. These are more or less confined to the silt layers, but are also present, but more highly oxidized, in the gravels. (Figure 20.)

Summary.

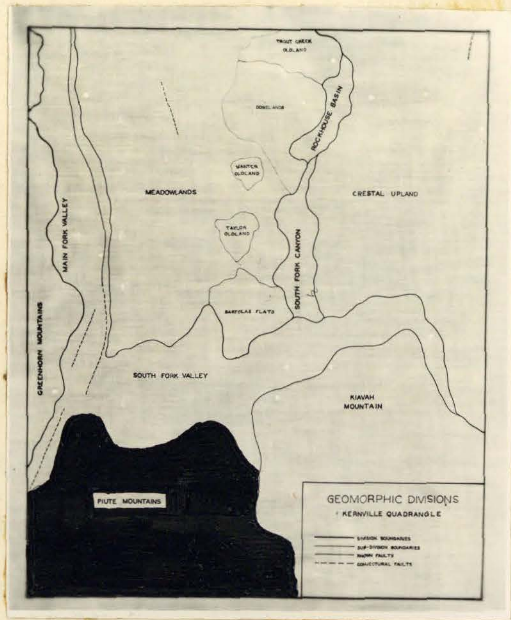
The Crestal Upland province might, as one can see from the characters just described, be considered part of the Meadowlands province. It was included in a separate subdivision, however, because it seemed: first, that it was distinctly lower in average elevation than the Meadowlands; second, it was separated from the Meadowlands by a pronounced linear depression, the Rockhouse basin; third, because it does not present the appearance of an irregularly dissected plateau; fourth, it contains a central ridge that is distinctly higher than its eastern margin, and deep interior valleys; and fifth, because of its heterogeneous rock character.

Figure 19. Long valley, on the Crestal Uplands, looking south.

Figure 20. Grits, sands, and silts in Lamont meadow, trenched by Chimney creek.

Piute Mountains.

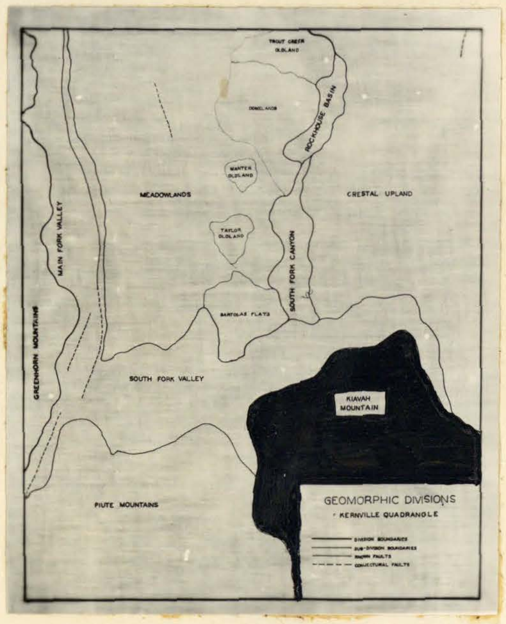
The Piute mountains, although outside of the area of detailed study, have been reconnoitered, and it is appropriate therefore to give a brief description in this paper. The summits of the range are similar in form and position to the higher parts of the Meadowlands surface. Inasmuch as this province is separated from the Meadowlands by the South Fork valley, it seems that this valley is but a breach in what was once a continuous surface, and that the Piute mountains are in reality part of the Meadowlands province.



Location, Piute Mountains.
(Figure 21)

Kiavah Mountain.

A broad flat-topped area south of the South Fork valley and to the east of Piute mountains has been investigated. This surface is separated from the Piute range and the Meadowlands by the South Fork valley. It lacks the large meadows of the main Meadowlands province, but has the same flat surface so typical of the Bartolas flats. It also lies at the same elevation.



Location, Kiavah Mountain.
(Figure 22)

It is thus apparent that Kiavah mountain is part of the Meadowlands surface, and was, before the breaching by the South Fork valley of the Kern, continuous therewith.

Migration of the Crestline of the Range.

In the present cycle of erosion, the highest part of the region is, as has been indicated, the summit of the Meadowlands province. It is, however, not the division of drainage as one might expect. The divide is the summit of the Sierran escarpment, from which, to the east, all streams drain into the Great Basin; to the west, into the San Joaquin valley. Thus, the Meadowlands block drains in opposing directions, but eventually to the same basin. It seems probable at an early stage in the deformation of the Nevadian matureland, that the crestline must have been the present Meadowlands summit, in that all surfaces slope away therefrom, and that, upon development of the Sierran fault, the crestline migrated eastward, leaving an older original crest, in favor of a new divide. Thus the Sierra has in the southern regional a dual crest, such as is commonly found to the north in the form of the Great Western Divide and the Whitney crests respectively.

Summary.

Evidence has been presented to justify the subdivision of the Kernville area into ten geomorphic provinces. The features of these units have been described, and suggestions offered as to their mode of origin.

Correlation of Geomorphic Features.

Correlation of Geomorphic Features.

Correlation of Surface Features Within the Area.

Brief mention should be made of some probable correlations of forms discussed above, most of which have been anticipated by statements made in the explanation of specific problems.

Remnants of the original oldland reduced in the final cycle of the Nevadian mountains are preserved on the summits of the Meadowlands province, the Greenhorn mountains province, and on the eastern edge of the Crestal Uplands. The summits of the Piute and Kiavah mountain provinces also show surfaces that are deemed equivalent. The writer correlates these with considerable confidence because (1) they lie at similar elevations, (2) they are preserved on the highest elevations of the range, and appear to be the oldest preserved surface, and (3) they are all in the same topographic stage.

The oldland remnants which extend north and south along the Main and South Forks of the Kern are correlated. This is justified because (1) they lie at similar elevations, (2) they have similar topographic characters, and (3) they may be explained logically as a result of the same geologic event. (See map of geomorphic provinces.)

Correlations with Other Regions.

Lawson (1904), in his paper on the Upper Kern, defines three hypsometric zones, called the High Mountain zone, the High Valley zone, and the Canyon zone. It appears that these surfaces have equivalents in the southern region, as they can be traced southward in each case.

The High Mountain zone of Lawson has been traced southward by the writer (on foot) into the Kernville area. The summits of the Meadowlands province lie in this zone. By inference, therefore, placing of the summits of the Greenhorn, Kiavah, and Piute mountain surfaces in the High Mountain zone is suggested.

Lawson places the Chagoopa plateau and the surface of the lava flows in the Little Kern basin in the High Valley zone. The writer disagrees with Lawson's correlation of the surface of the Little Kern plateau with the Chagoopa uplands because (1) the surface of the lava flows break the longitudinal profile of the High Valley zone when continued to the south, but (2) when the surface at the base of the flows are assumed to belong in the High Valley zone the longitudinal profile of the High Valley zone is without a break, (3) the geomorphic events recorded along the Kern canyon fault (see p. 62) indicate a much more recent date for the lavas than could be possible if their surface and the Chagoopa surface were equivalent, (4) the lava surface does not have the characters of one of planation by erosion; its characteristics are those of the surface of a lava flow, (5) Lawson's correlation would leave the surface at the base of the lava flows without equivalents anywhere else in the entire region. Thus, the writer believes that the evidence points to a correlation of the surface on which the Little Kern lavas lie, with the Chagoopa surfaces.

If the writer is correct in this determination, then one may with confidence place the oldlands along the Main and South Forks of the Kern in Lawson's High Valley zone, in that they are present the entire length of the two streams and grade one into the other. Valley surfaces which lie on the headwaters of the South Fork were placed by Lawson in the High Valley zone. Similar surfaces are found many places along its course. On the Main Fork, the Chagoopa plateau continues southward at lower levels (only remnants preserved) which merge with the oldlands of the Main Fork of the Kern.

The Canyon zone of Lawson includes the present canyon of the Kern. Its correlation along the course of the stream is obvious. The South Fork of the Kern also falls in this zone.

The three hypsometric zones defined by Lawson (1904) are used by Knopf (1918) in his work on the eastern slope of the Sierra Nevada. He finds that surfaces on the summits may be placed without discrepancy into this classification. This is to be expected, however, in view of the proximity of the region for which the classification was proposed and the area of Knopf's study. Knopf further suggests that the oldland surface of the western part of the northern Sierra (the peneplain of most writers) which was described by Lindgren (1911), is the correlative of the High Mountain zone (Summit Upland subdivision). Reid (1911), in the Lake Tahoe region, correlates high summit flats with the western oldland of the northern Sierra. Lawson (1904) has also suggested a similar correlation with the western Sierran "peneplain" and the High Mountain zone. Thus it seems that the High Mountain zone is present in many places throughout the Sierra.

Baker (1912), in a discussion of some Sierran features south of Walker pass, says (p. 137):

> "From the summits above Walker Pass one looks out to the east, north, and west over broad-topped summit mountains. These broad summits have a gently rolling topography manifestly the product of an older erosion cycle than that which formed the valleys which have isolated these peaks one from the other. This old erosion surface is apparently, although not certainly, the same as that of the Chagoopa Plateau described by Lawson in the Upper Kern Basin . . . ."

Thus Baker correlates the Chagoopa plateau with the summit uplands of what the writer has described as the Meadowlands, Greenhorn, Crestal Uplands, Kiavah, and Piute mountains provinces. This correlation has been questioned by Knopf (1918, p. 47) and will be shown by the writer to be in error. Baker then states that he believes the "Ricardo erosion surface" of Red Rock canyon to be a peneplain, and the equivalent of the above mentioned surfaces.

As pointed out by Knopf (1918), the chain of evidence on which Baker bases his correlation is weak, in that (p. 87):

> ". . . . the ancient floor of the Kern [Chagoopa Plateau] lies some 2,000 feet below the Subsummit Plateau and the Summit Upland, [these constitute the High Mountain zone] which together constitute the summit topography of the Sierra Nevada."

The writer supports Knopf with emphasis. The Chagoopa plateau and the summits of the southern Sierra can in no way be correlated. They may each be traced into their respective provinces within the Sierra; the Chagoopa into its equivalents in the High Valley zone, and the High Mountain zone into its southern equivalents on the summits of the southern Sierra in the region where Baker made his study. Baker's chain of evidence would be acceptable if he had correlated his "Ricardo peneplain" with the High Mountain instead of the High Valley zone.

Anderson (1933, p. 104), in his work on the White mountains, tentatively correlates the "Pellisier erosion surface" of the White mountains summits with the High Mountain (Subsummit plateau) zone of Lawson, although, as pointed out by Anderson (1933, p. 103):

> "The attempt to correlate erosion surfaces, being based mainly upon deduction without possibility of corroboration, usually leads to dubious results."

The Geologic Time Involved.

Introduction.

The results of the writer's studies in the southern Sierra Nevada have produced nothing in the way of actually dating the events which have been recorded in this thesis. No fossils have ever been found in any of the formations; true indurated sedimentary rocks are lacking. Wherever geomorphic or structural features are bevelled by erosional surfaces, or are buried by volcanic rocks, the age of the extrusion remains in doubt. Thus, considerations of age are but deductive inferences, that can be taken as suggestions only, and these dominantly as a result of work of other's rather than of the writer.

The acceptance or rejection of age determinations of erosion surfaces based on deductive inference, is tempered almost entirely by the school of thought in which the person who presents the age determination has been trained. If one has been taught to believe that traces of erosional levels may endure for long periods of geologic time (say, through the whole of the Tertiary), then he will be inclined toward an earlier date for the oldest erosional surface found in a given region. If, however, he believes that erosional uplands have their traces quickly removed, he will be inclined to give a later age to the erosion surface, and maintain that no erosional surfaces may endure through an entire period. Thus, in spite of some inductive reasoning from observed and proven evidence, the status of our opinions regarding age in its determination from erosional surfaces, is still formational. If, and when, new criteria are brought forth which will allow us to date igneous rocks without the now necessary sedimentary associations, then, and only then, may age determinations be made with accuracy in areas of crystalline rocks.

The Time Relations.

Many workers have offered estimates of the age of the Sierra Nevada. The highest preserved erosional surface in the range has been dated from the late Cretaceous (Lindgren, 1911), to Pliocene (Lawson, 1904). Matthes (1930), working in the Yosemite region, considers a peneplain recognized there as of Miocene age. Lindgren (1911) considers the oldest surface observed as late Cretaceous, and the next, or Sierran peneplain, as Tertiary. Reid (1911), in the Lake Tahoe region, correlates the summit uplands with the earliest surface of Lindgren. Knopf (1918) agrees with the Tertiary age of Lindgren's second erosional surface. Knopf's views are shown to be influenced by an eastern school of thought when he says that: (1918, p. 88)

> "For the facts established by Lindgren . . . . show that the drainage was rejuvenated . . . . probably late in the Miocene. This date Lindgren believes is more in harmony with the length of time indicated by the great erosional work performed since the uplift; it assuredly does less violence to our ideas concerning the length of Quaternary time than does the assignment of a post-Pliocene age as suggested by Lawson (1904) to the initial uplift and the westward tilting of the range."

Baker (1912), as indicated above, correlated the highest surfaces studied by the writer with those of the High Valley zone of Lawson, and in turn correlated both with the "Ricardo peneplain" which he assigned to post-Miocene time on the basis of vertebrate fossils. Thus, in Baker's determination, the surfaces next younger than the highest erosional levels of the Sierra Nevada are placed as of at least early Pliocene age. If, however, the correlation offered by the writer [which shows Baker to be in absolute error, and which has been previously questioned by Knopf (1918, p. 87)] is correct, then the highest summits of the Sierra Nevada are dated as equivalent to the "Ricardo peneplain" and must therefore be considered early

Pliocene. This would, of course, place the initial uplift of the Sierra in the early Pliocene. Baker's age determination for the Ricardo surface seems still to be acceptable.

It must be stated, that the writer realizes the inadequacy of evidence for the dates. They may give a relative idea of the time involved in the initiation and development of the Sierra from its Nevadian roots.

Summary.

Correlation of the Meadowlands, Bartolas Flats, Kiavah mountain, and Piute mountains surfaces is suggested. They are shown to belong in Lawson's High Mountain zone. Oldlands along the Kern and South Fork of the Kern are correlated and placed in Lawson's High Valley zone. The Canyon zone is also present in the Kernville area. Baker's correlations are shown to be in error for the Summit upland of the Sierra and the Chagoopa surface in the High Valley zone.

A Pliocene age for the Summit uplands of the Kernville region is suggested.

STRUCTURAL GEOLOGY.

STRUCTURAL GEOLOGY.

The Kern Canyon Fault.[1]

Introduction.

Field work in the Kern river canyon has shown that a large fault follows the eastern margin of the canyon from Kernville northward. It is the purpose here to describe some of the important features of the fault and to discuss its characteristics in the twenty-two miles along which it has been examined in detail.

Previous Geologic Investigation.

Apparently no detailed observations of the Kern canyon fault have been made. In 1902 Lawson made a reconnaissance trip along the canyon of the Kern, from the area south of Kernville to near its headwaters. He published the results in two papers (1904; 1906, 1) on the geomorphology of the middle and upper parts of the canyon. To interpret the forms in the area studied, several possible hypotheses were discussed, and it was concluded that the placing of a fault in the position suggested by the physiography best fitted the observed and inferred facts. Only physiographic evidence for the existence of the fault was presented, however. A paper by W. J. Miller (1931) mentions the influence of faulting in the region.

Location and Extent of the Fault.

The Kern canyon fault is a north-south structure located approximately halfway between the eastern and western margins of the Sierra Nevada

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1 Not to be confused with the Kern river fault, which crosses the mouth of the Kern river at the point where it enters the San Joaquin valley. See Blackwelder, E.: Scarp at the Mouth of Kern River Canyon, (abstract); Geol. Soc. Amer. Bull., Vol. 38, p. 207, 1927.

block (plate IX). It parallels closely the marginal faults on the west and the Sierra Nevada fault on the east, and is, so far as the writer is aware, the largest fault within the southern Sierra Nevada that trends parallel to the marginal faults. It is also one of the few long faults within the southern part of the range.

The fault is definitely known to extend from Kernville to the mouth of Golden Trout creek, forty or more miles to the north. South of Kernville its presence is doubtful, as only weak physiographic evidence for its presence can be found. However, it is possible that it extends as far as the south end of Hot Springs valley.

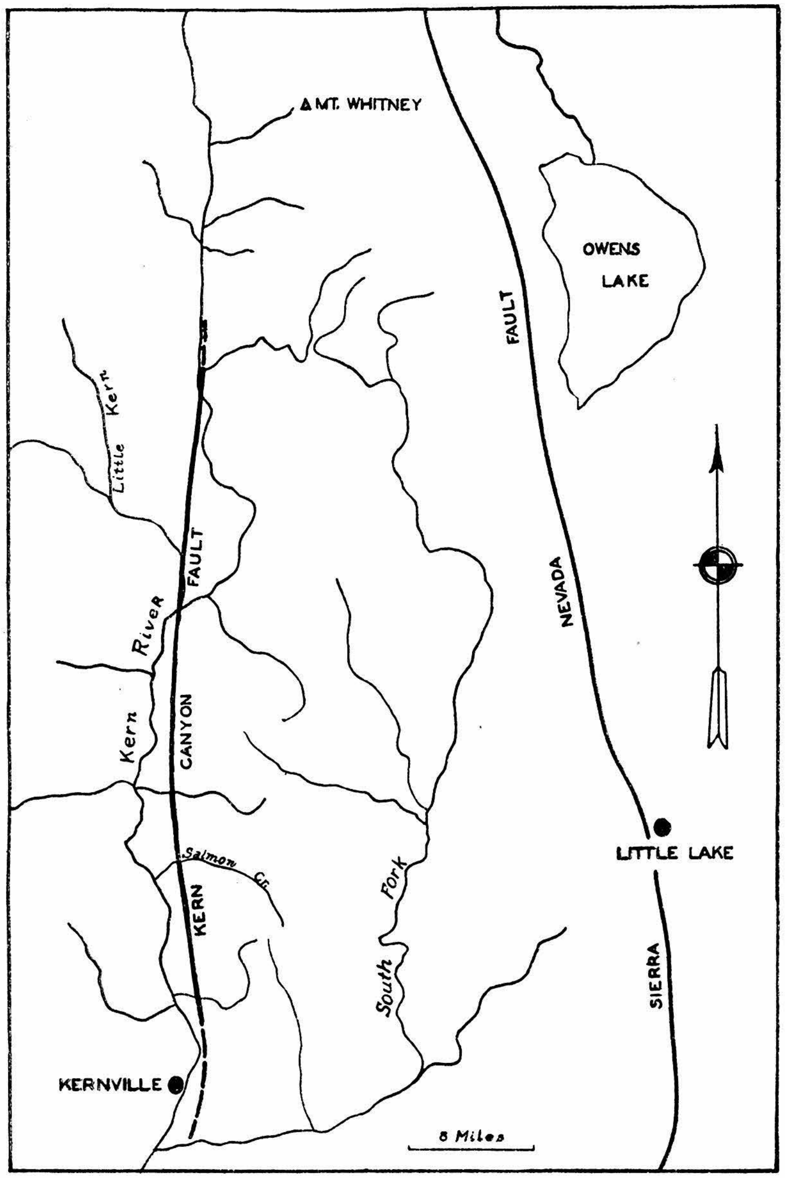
Evidences of the Fault.

Physiographic Evidence.

The Scarp: The eastern wall of Kern canyon for a distance of over twenty miles presents a bold, steep, frayed front, which, although considerably modified by erosion, rises more than 2500 feet above the trace of the fault, and 3000 feet above the channel of the river. The scarp varies in height, attaining its maximum in the vicinity of Salmon creek, and dies out northward near the confluence of the Kern and Little Kern rivers. The variable height, and other evidence discussed below, indicate the fault-line character of the scarp.

Discordant Profiles of Streams Crossing the Fault: Profiles of the streams flowing from the eastern block into the Kern show marked gradient changes at the fault line. This is in contrast to the western tributaries of the Kern, whose gradients, although steep, are uniform from head to mouth, even where downcutting of the Kern river has been most rapid.

Plate IX.



Map showing location of Kern canyon fault.

From the eastern block, the stream with the greatest break in profile is Salmon creek, one of the longest of the eastern tributaries of the middle Kern. It heads in a large meadow, nine miles east of the scarp. From its source to the brink of the scarp its gradient is approximately 100 feet to the mile. In the next mile the gradient changes abruptly to 2500 feet, while in the last mile to its junction with the Kern the fall is only 400 feet. The abrupt gradient change at the top of the scarp produces a waterfall about 125 feet high and then steep cascades. Cannell creek, to the south, and Packsaddle creek, to the north, also show such gradient changes; but they are less pronounced.

These gradient differences are, no doubt, in part due to rock differences along the stream courses. However, tributary streams from both sides of the Kern flow through granitic rocks for the major part of their courses and through metamorphic rocks in their lower courses. Profile breaks occur only in westward-flowing tributaries. Thus a structural difference must account for the convex-concave profiles of the eastern tributary streams.

<u>Line of Cols and Canyons along the Fault Line within the Canyon of the Kern, with Resulting Trellis Drainage</u>. As described by Lawson (1904, p. 405), a line of defiles occurs east of the canyon of the Kern. These are at the base of the scarp and are separated from the Kern river by a median ridge, through which the eastern tributaries flow to reach the river. Small lateral streams of the Kern river tributaries flow north and south along the fault line, producing a rectangular drainage pattern. The alignment of canyons persists along the entire known trace of the fault, and is a dominant physiographic anomaly for more than thirty miles northward from Kernville.

Figure 23. Looking south from Salmon creek along Kern canyon fault. Fault-line scarp on east.

Figure 24. Saddle, just north of Cannell creek, along Kern canyon fault. Looking south.

Structural Evidence.

<u>Rock Difference Adjacent to the Fault</u>: The line of the fault marks the boundary between the granodiorite, which makes up ninety per cent of the surface rock of the eastern block, and the more complex crystalline formations (chiefly the Kernville series and associated dioritic and gabbroic intrusives) of the main canyon of the Kern. It should be pointed out, however, that this petrologic relation is not everywhere present, which indicates that an intrusive contact cannot be responsible for the physiographic form. Five miles or more south of the junction of the Kern and Little Kern rivers, the Kernville series, which lies against the fault on the west side from Kernville northward, narrows and finally dies out. Its place is taken by granitic rocks, an extension of the granites and granodiorites of the east side, through which the fault passes. Here, as to the south, canyons have been eroded along the fault line.

Lawson (1906, 2, p. 406) pointed out the mixed character of the crystalline rocks of the Kern canyon in its middle part; that the line of defiles indicating the fault was also, in part at least, a petrologic boundary was apparently not fully appreciated.

<u>Discordant Attitude between the Kernville Series and the Fault</u>: The dip of the beds of the Kernville series one-quarter of a mile from the fault is nearly vertical; the strike is N45°W, making an angle of 45° with the strike of the fault. At the fault line, however, the deviation of strike is only 10°, and the dip changes from vertical to 45°. This feature is well shown from Salmon creek northward for six or seven miles. Movement on the fault undoubtedly produced this discordance, probably at the time of formation of the fracture.

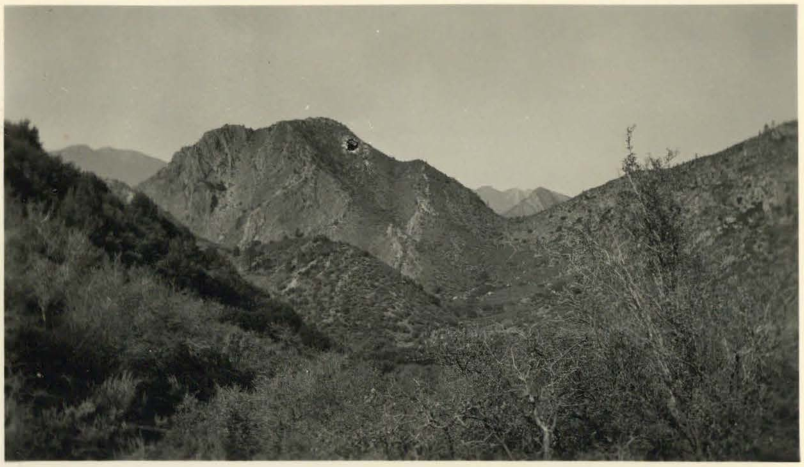


Figure 25. Looking north along Kern canyon fault across Packsaddle canyon. Note structure of formations.

Figure 26. Looking north along Kern canyon fault from saddle in background of figure 25, across Brush creek, along Kern canyon fault.

Jointing: Jointing is the dominant minor expression of the fault. In the area near Salmon creek, where the scarp is best developed, joints parallel the trace of the fault for at least one-quarter of a mile on the east, crossing the ridges and canyons of the eroded scarp. Many of these joints show evidence of minor movement. To the south, near Kernville, extensive sheet jointing in granitic rocks and along contacts of the Kernville series and the granitic rocks is parallel to the strike of the fault. The width of the canyon in the vicinity of Kernville is also believed to be due, in part at least, to the system of master joints and possibly to branch faults. Certain intrusive contacts on the extension of the trace of the fault that are remarkably straight, and sheared, are believed to have been affected by the fault movements.

Breccia, Mylonites, and Alterations: Along the line of faulting weathering has been so extensive that evidence in bedrock is hard to obtain; the brush cover adds to the difficulty. In one or two places, notably at the point where Salmon creek crosses the fault, a zone of extensive brecciation and complex jointing may be traced toward the river (west) into the median ridge; this zone in turn grades into a belt, composed of altered and sheared crystalline rocks.

Miscellaneous Evidence.

Warm Springs: At several places along the fault, especially just north and south of Kernville, warm springs emerge from sheared zones, particularly in granitic rocks, and also from alluvium covering the projected trace of the fault.

Activity of Solution: Near the fault, in areas of marble within the Kernville series, are found marble caves of considerable size, and coarse limestone (marble) breccias. It is thought that the caverns are the result of solution by waters migrating upward through channels and fissures along the fault. One large cave, called Packsaddle cave, occurs in Packsaddle canyon less than one-eighth of a mile from the fault line. Huge limestone breccias are common, especially along the trace of the fault north of Brush creek, where limestones are particularly well developed. Marble areas at a distance from the fault do not show these characteristics.

Coincidence of Fault and Intrusive Contact.

Inspection of the fault trace, in the twenty-two miles of detailed study, shows that the fault is in places coincident with an intrusive contact between the granitic rocks of the Sierran batholith on the east and the weak zone of metamorphic rocks on the west. The fault is distinctly marked, and under no circumstances is it possible to interpret the observed forms, nor to account for the broken zones, without faulting. It is logical to expect a fault to follow a pre-existent line of weakness. The fault is, however, not everywhere absolutely superimposed on the intrusive contact. Elsewhere rocks of identical kind are present on both sides of the fault.

Plan of the Fault.

Within the area of detailed study, branch faults are conspicuous by their absence. No subsidiary zones were observed, and the major fault is confined closely to the line of defiles which is its topographic expression. South of the area of special examination, however, several branch faults are suggest,ed by the character of some intrusive contacts, and major topographic expressions, such as Split mountain. (See geologic map.) The presence of a single fault zone is certainly denied by the physiography south of Kernville.

In the area of detailed study, an intrusive contact of considerable regularity, along the fault, undoubtedly is a dominating factor in the confinement of the fault to a single line, north of Kernville. North of the area of special study the trace of the fault is also a single line, but is not coincident with an intrusive contact.

Character of the Scarp.

It has been stated that the Meadowlands block is bounded on the west by a high escarpment, down which streams plunge with a discordant break in gradient of nearly 3000 feet. It is inferred that the escarpment is due to erosion along a structural line long after movements on the fault ceased. The scarp, which is being increased in height, is, thus, a fault-line scarp.

Evidence that the escarpment found along the trace of the fault is a fault-line scarp is as follows: (1) The height of the escarpment varies from place to place along the trace of the fault. (2) The scarp occurs throughout its length on the same side of the fault, but it has its greatest height where weak rocks are present on the lower side of the escarpment. (3) Blackwelder (1928, p. 308), in a notable paper on the criteria for the recognition and distinction of fault from fault-line scarps points out that if it can be shown that movement on the fault was pre-Pleistocene, good proof of a fault-line scarp is present. He cites the case of the Hurricane fault in northern Arizona, along which

> ". . . . Davis (1913, p. 210), and others have shown that the fault was base-levelled and the trace then covered by a Miocene lava flow which has not subsequently been dislocated. Differential erosion along this old line has, however, largely reproduced the scarp."

This point seems applicable to the Kern, in that (4) To the north, at the

Plate X.

Fault-line scarp along Kern canyon fault, at Salmon creek. Salmon creek falls are seen in the picture. Note notch cut by stream at crest of scarp.

point of confluence of the Kern river with the Little Kern (Plate IX), a series of lava flows covers the trace of the fault. These flows are not the most recent of the later volcanic rocks of the southern Sierra; they may be Pliocene in age. They are not broken by the fault; and prior to the extrusion of the lava, the fault trace was beveled, so that the lavas lie on an oldland surface. Thus the date of the fault displacement is set at pre-lava, which corroborates according to Blackwelder's theory the argument in favor of a fault-line scarp. (5) The corresponding elevation of surfaces on the two sides of the fault south of the junction of the Kern and Little Kern rivers indicates that no movement has taken place since the fault was beveled. (6) There is no evidence of recent movement anywhere along the fault. Thus, the evidence indicates that the face rising from the trace of the fault is a fault-line scarp.

It seems certain, in all cases where escarpments are present along the fault, that they are of fault-line character, but, as pointed out by Blackwelder (1928, p. 309),

> ". . . . the recognition of a fault scarp does not depend upon the blind application of a few convenient rules, but generally requires a critical analysis of complex data, among which there may appear to be conflicting elements which need to be reconciled. The necessary first step . . is to realize that fault-line scarps are in general commoner than fault scarps, and that the former resemble the latter in most respects, although they are entirely different in origin."

Thus the determination of any escarpment as a fault-line scarp is at best a difficult task. The writer feels confident, however, that the observations reported above are accurate, and that they tend to show that the exposed faces along the Kern canyon fault are fault-line scarps.

Displacements along the Fault.

The presence of a fault-line scarp along the Kern canyon fault indicates with certainty the existence of the fault in at least two cycles of erosion. Thus it is to be expected that the character of the displacement would be difficult to ascertain. No evidence has been uncovered to give any clues as to how the fault moved, since no formations are present that can be correlated across the fault. The change in attitude of the Kernville series as the beds approach the fault, as discussed above, may be an indication of the character of movement, but it is not sufficiently definite to lead to any conclusions.

A Fault Line versus a Crustal Rift.

The evidence of faulting along the Kern river canyon has been presented. The writer's observations extending all along the known trace of the fault, have led him to believe that the fault in question is confined very closely, with no known branches, to the line of defiles within the canyon and east of the Kern river itself, lying at the base of the Meadowlands escarpment. Professor Lawson (1904, p. 336; 1906, 1, p. 409) has, on the other hand suggested the presence of a crustal rift which he believes has determined the course of the Kern river. Upon analysis of the evidence suggested by Lawson, and the testing of this hypothesis, the writer finds no support therefor.

The original statement of the rift hypothesis was made in Lawson's first paper on Kern river geomorphology (1904). In application of this hypothesis to the fault line, Lawson suggested that graben features exist along the fault line; the fault, he believed, determined the trend of the canyon of the Kern. It is the writer's view that the present canyon of the Kern is a much wider and larger valley, at least in the southern part, than the one eroded along the fault line.

The rift hypothesis as advocated by Lawson for the upper Kern might be acceptable in view of the facts, except for his extension of the influence of the rift to the south, into the area of detailed study. First, it is difficult to see from the use of the term 'rift', just what is implied. (He apparently means a narrow zone, along which no vertical displacement is apparent on the margins, but <u>in which</u> vertical movement takes place.) From the trend of the evidence and discussion of working hypotheses in the paper, it seems that by 'rift' is meant a distinct graben, bounded by two or more faults, which is part of a 'rift fissure'. Lawson (1906, 1, p. 409), in his second paper, extended his rift hypothesis to cover the area of detailed study. He states that:

> "For the Upper Kern the conclusion was reached that the canyon had been controlled as to its course by a rift line antedating the cañon and that at a later period faulting had occurred along this rift with partial engulfment of a narrow orographic block or wedge. The Middle Kern lies along the southward projection of this rift line through the Trout Meadows defile, and there seems little room for doubt but that its course, like that of the Upper Kern, was determined primarily by a great north-south crustal rift. At a later period when the canyon had been deeply incised the region was deformed and dislocation was effected along the general line of the rift."

Thus he definitely implies graben structure, or rifting at least along small blocks bounded by faults, for the middle Kern. This is further evidenced by the statement made in connection with the origin of forms present on the west side of the Kern canyon at the base of the Greenhorn block, that (Lawson, 1906, 1, p. 403)

> "It is even quite probable as an inference from the existence of these cones [at the base of the

> Greenhorn province] that, if the country a few miles back from the stream were examined, a fault scarp would be discovered, ..."

It seems reasonable to infer from this that if such a fault existed, it must have been the western bounding fault for the crustal rift. A careful search was made of the eastern base of the Greenhorn mountains for such a fault; no evidence for it could be found. It is possible that Lawson does not consider the suggested fault at the base of the Greenhorn mountains as one of the faults of the rift system. If so, then the rift must fall in the line of defiles on the eastern edge of Kern canyon. However, no evidence was found, at least in the middle Kern, to show the existence of a crustal rift along this line.

Dr. Matthes, of the United States Geological Survey, who is working in the region of the upper Kern informed the writer[1] that he found no evidence of crustal rifting in the upper Kern canyon. Thus it seems that the evidence shows the presence of a single fault line, and not a crustal rift, along the canyon of the middle Kern.

Out of fairness to Professor Lawson, it must be remembered that his papers report results of reconnaissance work only, conducted in a short time, over a wide region, and that many of the ideas expressed are not presented with certainty, but as suggestions that seemed more nearly to satisfy the broader observations made.

Relative Time of Movement along the Fault.

There is no evidence of recent movement along the fault. It is true that earthquakes have been reported and confirmed in the region. It is likely that local adjustments in the alluvium of Hot Springs valley are taking

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1 Personal communication.

place. On July 6, 1935, a slight shock was felt in the region around Kernville. It was described by Dr. Ruth E. Baugh, Assistant Professor of Geography at the University of California at Los Angeles, as:[1]

> "An abrupt jolt, lasting several seconds, coming between 9:10 and 9:15 p. m."

On the same evening, the writer was encamped on the summit of the Meadowlands block, less than ten miles distance. The shock was not felt by any of the field party. It is inferred that it was of local origin (such as an adjustment in the alluvial plain formed at the junction of the South Fork and Main Fork of the Kern) as it seems likely, had it been a movement along the Kern canyon fault, that it would have been felt over a larger area. Thus the writer does not feel inclined to accept this recent seismic activity as proof that adjustments are still taking place along the Kern canyon fault. The fact that no physiographic indications of movement of any kind are present, makes the conclusion of the ancient age of the fault movement seem a valid concept.

The lack of evidence of the time of the fault displacement is supported by the statements of Lawson (1904, p. 342) of conditions in the upper Kern. He says:

> "We have no evidence that the Upper Kern follows the trace of a fault plane. There is no geomorphic or geologic evidence of any differential displacement of the country on either side of the Kern Canyon. A fault may possibly exist there, but if it does it must have been formed anterior to the evolution of the High Valleys of the region, since there is no perceptible discrepancy in level between the two portions of the Chagoopa Plateau separated by the canyon. But whether it exists or not is immaterial to the thesis that the Upper Kern follows a line of rifting."

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1 Personal communication.

Some of the suggestions of Lawson regarding probable time of fault displacement are not in accord with the evidence as observed by the writer in that Lawson (1904, p. 365) postulates that

> ". . . . Kern Canon is evidently controlled by some structural feature, which was probably established at the time of this second uplift. [He considers that an initial uplift took place along the Sierran fault, followed by an erosional pause, and then renewed movement.] This structure appears not to have been of the nature of a fault of sufficient throw to appreciably dislocate the High Valley floors. It is, therefore, suggested that it was of the nature of a rift fissure." [The different interpretation of the writer of the continuity of the high valley floors, is, of course, truncation of the fault line and regions adjacent after initial movement.]

However, prior to the FIRST uplift, Lawson (1904, p. 365) states that there were

> ". . . . volcanic vents opened in some of the high valleys [which] veneered their floors with sheets of basalt. The best example of this . . is the lava which lies upon the surface of the Little Kern Plateau and which has been subjected to the same dissection as the plateau itself."

These lava flats of the Little Kern plateau have been examined by the writer in reconnaissance. They show no evidence of dislocation by the fault, even though they completely cover a two mile or more seqment of the fault line, or rift fissure as it is called by Lawson. This seems to be positive evidence that the fault was established prior to the extrusion of the lavas of the Little Kern, and that no movement of any kind has taken place since their deposition. Thus the writer feels that the evidence contradicts an hypothesis which requires movement along the fault line after the extrusion of the lavas. Several epochs of movement may have been involved prior to their extrusion. If such is the case, the evidence has been long since removed by erosion.

Therefore, if, as stated by Lawson and supported by the writer, it is true that the lavas were extruded prior to the first uplift, then it is a contradiction of the facts presented by Lawson himself to state that the structural control of the Kern canyon was established at the time of the second uplift, because it has been shown that the beveled fault trace is covered by the lavas, with no movement since their extrusion; this establishes the fact that the Kern canyon fault was a pronounced and dominant structure before the first uplift of the present Sierra.

The fact that the lava flows are unbroken also proves (according to the writer's interpretation of the statements in the hypothesis of Lawson) that the fault line was present in the Sierra prior to the first uplift which affected the eastern equivalent of the western peneplain of the old Nevadian range. Thus, in the Lawson hypothesis (but apparently not recognized as true by him), the date of the faulting along the Kern canyon is set at pre-rejuvenation, and the fault must therefore have been present at the close of the Nevadian planation.

Explanation of Geomorphic Discordance of the Kern with the Fault.

Examination of the maps accompanying this report show at once that the present course of the Kern does not in any way follow a structural line. It is an irregular, meandering stream, which, although straight in general, contains irregularities inexplainable under an hypothesis requiring concordance with pre-existing structure. Further examination of the stream course in relation to the fault line shows that at two places the stream transversely cuts away from and across the fault line, and in no way seems to be influenced by it. The logical query is: "Why does it not follow the fault?"

It has been shown that the Kern canyon fault is an old fault of unknown displacement; that it has been planed off; and that along it a fault-line scarp has developed. In the early stages of deformation of the present Sierra the Kern cut a new valley in the oldland surface of the Nevadian roots. This valley is preserved as wide benches along the course of the Kern.

It is significant that no remnants of the oldland, developed in the cycle of erosion in the pause following the initial deformation, are present east of the Kern river in the area of detailed study. To the north, however, as shown by Lawson, extensive oldlands are found on the eastern side of the Kern. In the area of detailed study where oldlands are lacking along the eastern side of the river, they are present, though to a lesser extent, on the western side. It seems probable that, where the fault-line scarp is best developed, the exhumation of this scarp began in the first stages of downcutting following the initial deformation. Before this the Kern might have followed the line of the fault. When a base level was established in the first pause after the initial deformation, wide inner valleys were produced by the Kern. In the area of detailed study, the weak rocks lie west of the fault line. Thus all widening of the river course would tend to be to the west in the area of the high escarpment. To the north, where rocks of equal hardness are crossed by the fault, the river would tend to develop a wide valley over the trace of the fault more or less equally on either side. Thus, in the south, according to this statement, one would not expect to find preserved oldlands on the east side of the Kern valley across the fault line, since none were ever formed there. Any surfaces formed at that time which lay in the short distance between the fault and the river course, would as a result of the increased height of the scarp and the development of the median ridge, have been eroded away.

Thus it is clear, that, after the initial deformation of the Nevadian roots, sufficient time elapsed to permit the development of a wide mature valley, over which it is reasonable to infer, was deposited a thin film of gravel, such as those formed by streams that have reached grade. It is a fair statement that the graded valley extended far up into the present headwaters of the Kern. Over this wide graded valley floor, the Kern meandered. It is probable that the Kern occupied a slight channel cut in the gravel cover of the graded valley floor.

The fault-line escarpment in the southern area, formed, then, the eastern margin of the Kern canyon. Where the fault line was crossed by the Kern to the north, there would be no tendency for the stream to flow along the line, as a gravel covering over the entire floor had buried any surface expression of the fault line, and thus removed the influence of differential hardness from the stream. This was similarly true in the southern area where the escarpment was already somewhat developed.

Following the erosional period, rejuvenation of the southern Sierra uplifted the range as a great horst block. The rejuvenation, of course, caused the Kern to incise its channel along the course already followed in the alluvium. Thus the channel of the Kern was superimposed by alluviation (Gilbert, 1877, p. 144).

In the interval after the reduction to base level, and before or shortly after the beginning of the second uplift, lava outpourings took place which buried and preserved the surface of the valley of the older cycle. Unfortunately no buried gravels have as yet been found preserved beneath the lava.

It is possible that the lava outpourings, in part at least, deflected the Kern and forced it to assume a new course.

As uplift continued, the downcutting power of the Kern, naturally, was greater. The stream was thus superimposed by alluviation upon the underlying rocks of differential hardness and structure, across which the river now flows discordantly. Thus the channel of the Kern was superimposed.

It is highly probable that sometime during the Nevadian erosion of the pre-Sierran range, that the Kern followed the line of the fault. It is even more probable that the Kern initially followed the line of the fault in its downcutting to the base level established by the initial deformation of the Nevadian surface. These possibilities have no direct evidence to support them because evidence has been obliterated by long continued erosion. A reasonable inference, is, however, in view of the action of streams along other faults, to suppose that at some time or other the Kern did follow the fault.

The Origin of the Median Ridge.

On first considering the morphologic features of the Main Fork valley, the median ridge offers a problem, the solution of which seems difficult. However, once it has been established that the escarpment lying next east of the ridge is a fault-line scarp, a solution is immediately apparent.

In the course of the downcutting of the Kern, the base level of the tributary streams of the whole region was relatively lowered. Tributaries to the Kern from the increasingly high fault-line scarp along the Kern canyon fault began cutting down rapidly. As incision progressed, the smaller tributary streams developing deep channels in the bedrock west of the fault line were unable to widen their canyons because of the rapid downcutting of the Kern. At the same time, the Kern, a stream of larger volume, was able to do lateral, as well as downward work, thus developing for itself a wider canyon, with youthful tributaries. In the meantime, lateral streams to the tributary streams had found the zone of weakness occasioned by the fault, and had worked headward along the fault line, as subsequent streams. As erosion progressed, the lateral streams cut downward, thus increasing the height of the median ridge and of the scarp.

The median ridge should initially have had a surface which was lower than the elevation of the two adjacent uplands because it was levelled by the Kern when the inner valley was developed after the initial rejuvenating movement.

Possible Southern Continuation of Kern Canyon Fault.

South of Kernville, in Hot Springs valley the presence of a fault is suggested by several geomorphic anomalies which are described by Lawson (1906, 1). It may be reasonably asserted, as Lawson did, that the anomalous features south of Kernville, that seem best explained by faulting, are on the same fault as the known one north of Kernville.

Professor Buwalda, of California Institute of Technology, informed the writer[1] that he and Mr. H. O. Wood, of the Carnegie Institute Seismological Laboratory, in Pasadena, attempted to trace the fault to the south, but that no continuation could be discovered for which evidence was available.

South of Hot Springs valley, a transverse ridge of granitic rocks rises about 2000 feet above the valley floor. In this ridge a deep saddle, of symmetrical profile, has been eroded. Through this saddle passes a road leading from Hot Springs valley into Havilah valley. Along Havilah valley, Lawson (1906, 1) has suggested, on physiographic evidence, that a fault exists. The writer travelled along the supposed fault, and it seems that the

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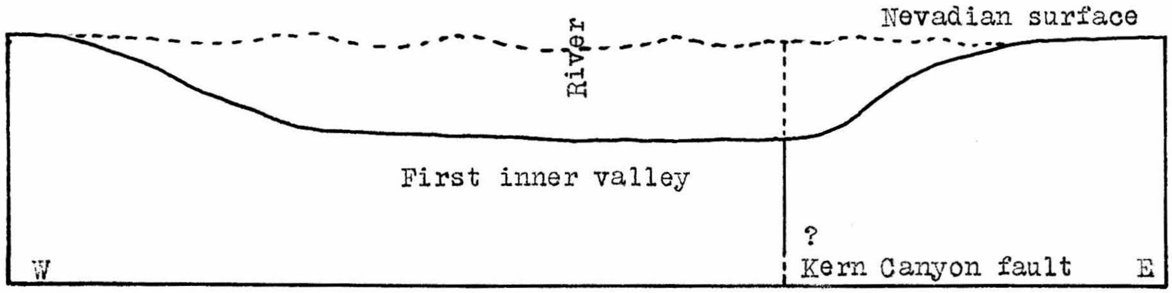
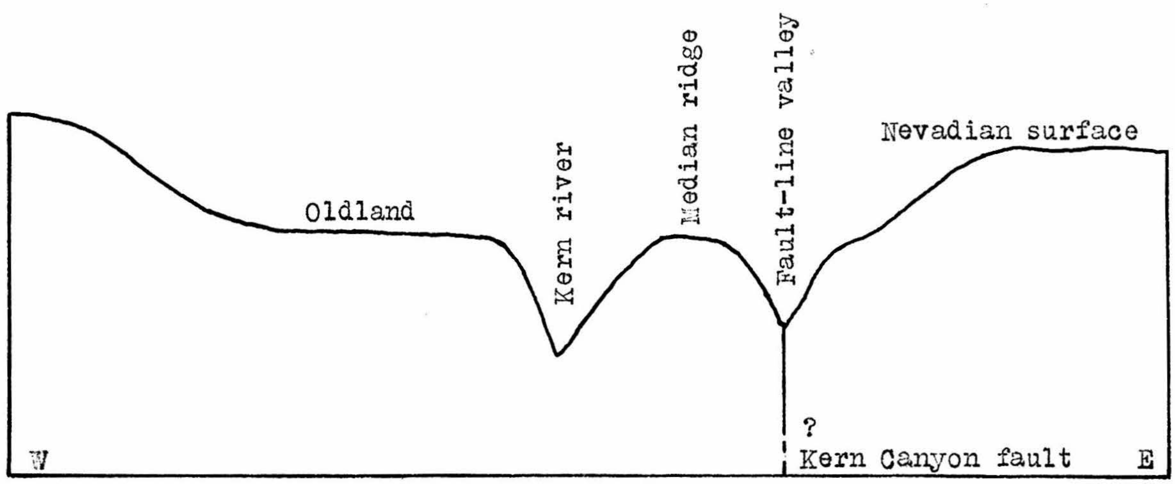
1 Personal communication.

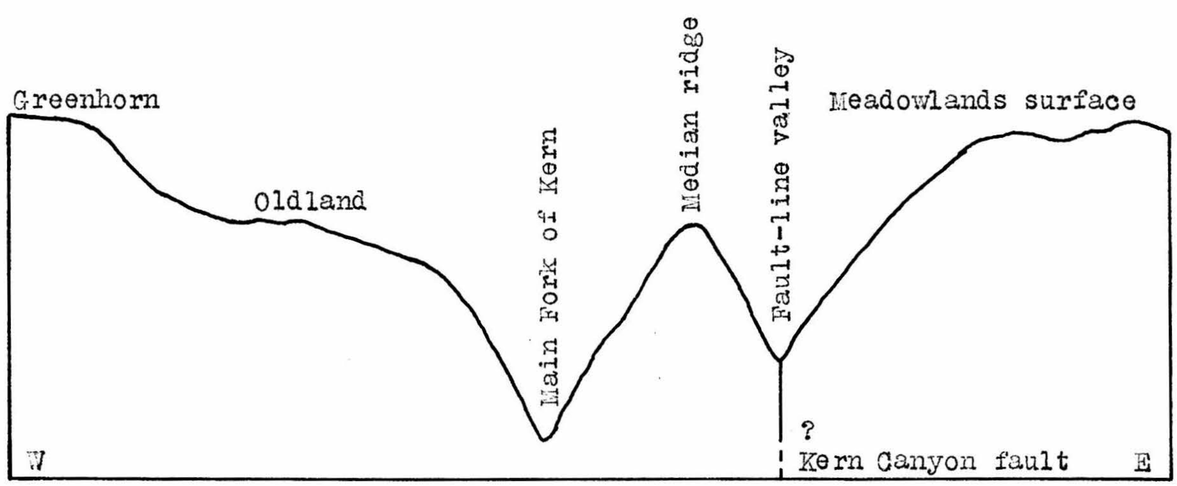
Plate XI. Diagrammatic east-west profiles across Main Fork of Kern, showing development of principal features.



After First Rejuvenating Movement



Renewed Uplift of Sierra



Present Condition

fault can be as well placed in one saddle as in the next one. Lawson believed that the fault in Havilah valley continued northwestward and terminated somewhere in the vicinity of the intersection of Havilah valley and the Kern river, rather than crossing the transverse ridge separating Havilah valley from Hot Springs valley.

Continuing southward across Walker basin and over the divide into Caliente creek, it has been suggested that a fault of large displacement lies along the southwestward continuation of Caliente creek; this has been discovered by well-drilling near the southern end of the San Joaquin valley[1]. The fault passes from the valley into Caliente creek, gradually disappearing in the crystalline rocks there encountered. This may be the continuation of the fault of Havilah valley.

In a trip along the line of this possible continuation of the Kern canyon fault, taken by the writer for the sole purpose of accumulating evidence in favor of the continuation of the fault as outlined above, so little evidence, even of a physiographic nature, was observed that it was concluded that a southern continuation cannot be justifiably postulated.

The northward continuation of the fault north of Kern lakes is not familiar to the writer. Dr. Matthes of the United States Geological Survey, who is now preparing a survey of the Sequoia National Park area, has studied its continuation, and he says that the influence of the fault is distinctly minor in the geomorphology[2]. This is in accord with the writer's observations that the fault dies out northward.

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1 R. D. Reed, Personal communication.

2 Personal communication.

The Durrwood Fault.

After much deliberation, it has been decided to indicate a probable fault at the base of the line of high peaks on the summit of the Meadowlands province, along the line of saddles extending from the vicinity of Durrwood meadows southeastward toward Big meadows. The evidence for this fault is shown by: (1) the abrupt rise of the backbone ridge of high peaks from the relatively narrow saddle and frontal ridge, which in turn rises abruptly from the Brush creek drainage along the Kern canyon fault, (2) the line of canyons and saddles parallel to the fault from Durrwood to Big meadows, (3) the many springs emerging along the line of the defile, which are sources for most of the water of the Brush creek drainage, (4) joints, parallel and sub-parallel to the trace of the fault, (5) the defile eroded along the proposed fault, which is sub-parallel to the Kern canyon fault, (6) the fact that the geomorphic features are more logically explained by erosion along a fault in the place postulated.

The Sacatar Canyon Fault.

A small fault is believed to coincide with a line of canyons at the extreme northeastern edge of the area, at the head of Sacatar canyon. This fault has no structural or geomorphic significance, in that it is less than one-half mile long and appears to have had little influence on the topographic history. Evidence for the fault is (1) a series of small rounded hills hugging the east side of the canyon, which are interpreted as kernbuts, (2) extensive brecciation of the rocks within the kernbuts, (3) a small amount of mineralization in the knolls, (4) sub-parallel joints in the face of the hills rising east of the kernbuts, which are parallel to the trace of the supposed fault.

The Sierran Fault.

The great Sierran (Sierra Nevada) fault lies outside the area of detailed investigation, and only cursory observations have been made thereof. It has been described by earlier workers and is included in the Searles lake quadrangle that is being surveyed by Professor C. D. Hulin, of the University of California. The Sierran fault in this latitude, however, shows none of the spectacular features induced by relatively recent movement, such as are found northward in the Owens valley region. At this latitude the scarp is extremely frayed, deeply eroded, with canyons extending far back into the range, which have long, alluviated lower courses and steep head gradients; they are still rapidly cutting headward into the summits of the Crestal Upland province. This part of the Sierran scarp has been briefly described by Baker (1912, p. 139), who points out that the area under consideration includes that part of the scarp which is transitional in nature between that area with evidences of recent movement to the north and that with older movement to the south. He says:

> "If one examines the stage of topography of the east flank of the Sierra west and south of Owens lake . . . . and compares it with the stage of topography of the east flank south of Walker Pass, one notes a remarkable difference. The eastern scarp of the Sierra in the neighborhood of Owens Lake is very precipitous, the base of the range approximates a straight line with no broad re-entrants along the drainage courses, or shoulders projecting out into the basin area between the drainage courses . . . . The topography of the Sierra from Indian Wells northward into and beyond Owens Valley is much more youthful than that of the section of the range from Indian Wells southwestward to Jawbone Canyon."

The Greenhorn Fault System.

The Greenhorn mountains fault system has not been studied by the writer. The system lies west of the area of detailed study at the base of the Sierra on the San Joaquin valley side. This system has been described by Hake (1928, p. 1028), and later by Miller (1931, p. 335), who says:

> "There is strong geomorphic evidence of a north-south fault fully twenty-five miles long extending from California Hot Springs (Tulare County) to past Glenville (Kern County) and along Poso Creek. The writer agrees with Hake, who states that a large part of '. . . . that scarp is the steep western flank of Greenhorn Mountain, which rises precipitously some 2,000 to 4,000 feet above the alluviated valley of Poso Creek which parallels the base of the Mountain.' That portion of the southern Sierra Nevada, therefore lying west of this fault has been uplifted far less than the larger portion lying between this fault and the Sierra Nevada fault."

The writer has examined the area where these faults are believed to be and he agrees with the geomorphic interpretation. No new observations were made.

Folds.

In a region of this type in which no true sedimentary rocks are present, the recognition of folded structures is made very difficult. In the Kernville series, of highly metamorphosed sedimentary rocks, one expects to find folding; but, as is often the case, beds have been so changed from their initial positions that recognition of the type of folded structures is impossible. In general, in the Kernville series, no positive evidence of intensive folding has been found. The formations in general, have very nearly vertical dips and regional strikes; whether these are isoclinally folded beds or whether they represent an upturned non-folded series is not definitely known. Lack of key beds in most cases make recognition of repetition of beds, if such is present, impossible.

Figure 27. Folds in the Fairview area of the Kernville series. Also note trenched alluvial fans.

Figure 28. Structure in the Fairview area of the Kernville series. The beds in the foreground and on the right strike north-south; those in the middle distance, east-west.

In the area of Kernville series, known as the Fairview unit, extensive development of well-defined marble beds, more or less continuous, enabled the writer to trace a large fold in the series. Aside from small intraformational corrugations, other folds were not observed, even in the Mine unit of the Kernville series where exposures are excellent.

Joints.

In several places in the region, joints are extremely well developed, especially in the exposures of granite and granodiorite of the main Sierran batholith. Efforts were made to observe a regional attitude of the joint systems. This was not successful. In the chapter of this thesis on petrology some attempts will be made to show the origin of jointing in connection with the emplacement of the batholithic rocks.

THE GEOMORPHIC HISTORY.

THE GEOMORPHIC HISTORY.

Introduction.

After considering the complex geomorphic, and structural problems involved in the region, the presentation of a geomorphic history that will satisfy the facts seems almost impossible. Since no worker has as yet attempted an explanation which adequately integrates all the geomorphic events, one will be presented, which, it is believed, very nearly harmonizes all the problems.

The Hypothesis of Hake.

Hake (1928) has offered one hypothesis for the origin of the southern Sierra. It seems to very nearly satisfy the general features observed by the writer in the course of this work, and he has leaned heavily on it in drawing up his own theory. It is notable that an hypothesis based on what was admitted to be reconnaissance work, should apparently so nearly satisfy the detailed study. The hypothesis as presented by Hake (1928, p. 1030) is as follows:

> "Deep-seated earth forces directed vertically upward caused the Tertiary uplift of the range to begin as a gentle swell or upwarp. This lifting of the crust first produced a range with a crest line somewhat west of the present divide, probably in about the location of the ancient peaks described by Lindgren, and continuing southward in the vicinity of the present Great Western Divide, which separates the Kings, Kaweah, and Tule rivers from the Kern. About the beginning of Quaternary time, after the range had attained a considerable height and an advanced stage of topographic development, tension produced in the upper crust by further upwarping caused fracturing and readjustment by normal faulting. This faulting was more profound on the eastern flank of the upwarp than on the western, and by virtue of the greater uplift on the east the divide was made to migrate

eastward. Displacement on the eastern flank was localized in a narrow zone, in which the great eastern scarps were formed. As the uplift was much less in the northern part of the range than in the southern part, the warping of the surface of the northern Sierra is not pronounced. The western fault system, being of smaller magnitude than the eastern one, either did not develop in the northern part of the Sierra or its effects are too minute to be readily detected among the grander topographic features produced by vigorous erosion on diverse rocks."

Hypothesis of the Writer.

Introduction.

It is now a generally accepted fact that the Sierra Nevada in its present form is a fault-block mountain range produced by rejuvenation of the eroded roots of the Nevadian mountains. Most of the geomorphic features which were formed prior to the rejuvenation of the Nevadian range have been almost completely obliterated. Thus, in these studies, little evidence of morphologic evolution is available for the geologic time prior to the beginning of the rejuvenation. The starting point is, then, by necessity, the erosional stage reached in the region before the rejuvenation began.

Character of Rejuvenated Surface.

The stage reached in the reduction of the Nevadian mountains before rejuvenation has been debated by a number of workers. It seems generally agreed, however, that only the western and northern parts of the Sierra were reduced to peneplanation, and that the southern and eastern parts of the ranges were in an earlier stage in the cycle at the time of rejuvenation. Thus Drake (1897) infers that the drainage areas in the southern Sierra had retained their characteristics when rejuvenation began. He says: (p. 570)

> "It appears that the southern end of the Sierras has existed longer as a mountain range, . . . that these drainage systems are older and naturally more basin-like or collected in larger groups."

Again, Lawson (1904, p. 363) apparently accepts the theory of the greater relief of the southern Sierra when he says that the Sierra Nevada

> ". . . . had been . . . . reduced to a region of very moderate relief, and on its western flanks was in a condition of a peneplain. The more eastern portion was, however, still a distinct, though low, mountainous country draining across the peneplain to the sea, and was higher to the south than to the north."

Stages in the Favored Hypothesis.

The stages in the favored hypothesis are as follows:

(1) The development of the Kern canyon fault along a north-south line, prior to the rejuvenation of the Nevadian mountains. This is known because the Greenhorn mountains summits, and the Meadowlands summits, are at the same elevation approximately, indicating no movement (vertically, at least) since their development.

(2) Production of the Nevadian oldland.

(3) Deformation of the Nevadian surface by a domal uplift whose crest was in the central part of the southern Sierra, roughly parallel to the present crest of the Meadowlands province. This deformation was in the form of a broad arch, extending beyond the limits of the present range. It rejuvenated the summit oldland and initiated a new cycle. The magnitude of the doming produced slopes less than 200 feet to the mile over a width of fifty miles or more. This estimate is based on the present heights of the summit of the Sierran escarpment, the actual crest (Meadowlands province) of

the range at the latitude of detailed study, and the Greenhorn mountains summit surface. The Sierran escarpment has an average elevation of 7000 feet. The average of the Meadowlands surface is 7500 - 8000 feet, and the Greenhorn province 7000 - 7500 feet. The difference of 500 feet between Greenhorn and Meadowlands elevations is not due to movement on the Kern canyon fault, as east-west summit profiles show no breaks where they cross the fault.

(4) A period of erosion in which the master streams and their master tributaries developed mature valleys in the rejuvenated oldland. The remnants of these valleys are the oldlands of the two Kern rivers.

(5) Extensive volcanism, especially along the valley of the Main Fork of the Kern, and in the Meadowlands province. Outpourings took the form of basic lavas and agglomerates, from different sources, not from a single vent. These lavas preserve valley remnants of the oldlands produced in step four.

(6) Development of the Sierran fault. As uplift progressed after the pause during which the oldlands were produced, there developed a huge fracture on the eastern margin of the Sierra. It is a reasonable inference that the rupture began in the region of present maximum displacement along the fault, and extended itself north and south therefrom. If such is the case, the initial development of the fault was in the Mount Whitney-Owens valley area. As the faulting continued, the range was tilted westward. The small amount of west tilt in the southern Sierra, superimposed on the domal structure, initiated a few westward flowing streams. This movement initiated the westward flow of the South Fork of the Kern. The tilting and doming may have overlapped in part.

(7) Contemporaneous with, or very shortly after, the development of the Sierran fault, on the west side of the southern Sierra there developed a series of step faults of relatively large total displacement, along which the entire region was uplifted, as a horst, with no renewed movement on the Kern canyon fault. This last movement brought the region to its present stage.

As a result of the marginal faults, the summit level of the Greenhorn mountains, which sloped westward after the doming, became re-levelled nearly to the horizontal. The re-levelling decreased the gradients of the streams flowing eastward from the Greenhorn block; similarly decreased were the gradients of the streams flowing westward toward the Greenhorn block, across whose courses the Greenhorn block straddled. This produced alluviation along the streams draining the Greenhorn mountains, and along the South Fork valley.

(8) Glaciation of the higher levels of the Sierra began sometime near the close of, or after, the rise of the range to its present elevation.

(9) A second epoch of volcanism, produced the recent volcanic cones found along the South Fork of the Kern (Toowa valley) and Golden Trout creek, in the Olancha quadrangle, contemporaneous with and following glaciation.

(10) Trenching of deposited materials has resulted in the present stage in the physiographic cycle by the lowering of the base level by normal erosion.

Summary.

The hypothesis presented above places the events recorded by the evidence in chronological sequence. It seems to explain the major problems encountered in the geomorphology. Until new facts are discovered which will invalidate the relations postulated, or which will clarify existing uncertainties, the writer believes the hypothesis will stand as accurately picturing events as they are now recorded.

PETROLOGY.

The Rocks of the Crystalline Complex.

Descriptive Section.

Metamorphic Rocks.

The Kernville Series.

Metamorphic Rocks.

The Kernville Series.

Introduction.

The metamorphic rocks belong to the Kernville series, a name proposed by W. J. Miller (1931, p. 335) for the meta-sedimentary formations exposed in the vicinity of Kernville, California. All of the metamorphic units have the same lithologic character and the same general attitude. There are five major areas of the Kernville series in the region, and several minor ones. The major ones are: The Mine area (T23S, T24S, R36E); South Fork area; Big Pine meadow area; Woodpecker area (T22S, R34E); Fairview area. (For precise locations of these see the geologic map in cover.) Minor areas are present near Kernville, and in the eastern part of the Meadowlands province.

Lithologic Types.

Meta-Conglomerate.

Meta-conglomerate occurs in several Kernville units. First reference to this type was by Miller (1931, p. 338), who described rolled gneiss from the southern part of the quadrangle. He says:

> ". . . . two and one-half miles east of the top of Cook Peak, some beds of what are believed to be conglomerate gneiss are interbedded with mica schist. Pebbles of quartz flattened to one-half of an inch wide and three inches long occur in the gneiss."

The largest area of rolled gneisses occurs on the summit and slopes of 7285 hill (T23S, R36E, sec. 6). The rock consists of quartz pebbles from one-half to three and four inches in length, and from a fraction of an inch to one inch in width. The matrix consists of quartz. For the most part

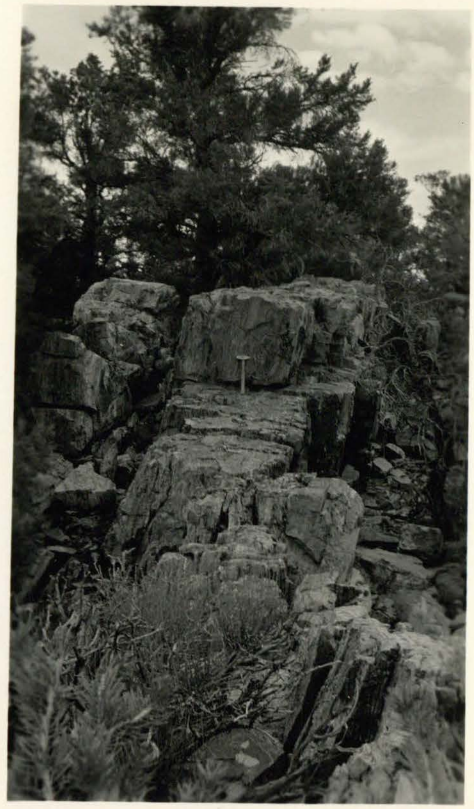


Figure 29. Outcrop of rolled gneiss, summit of 7285 hill. (T23S, R36E, sec. 6.)

Figure 30. Typical outcrop of quartzite. Near Woodpecker meadows.

the rock is very pure. Elongation of pebbles parallels the strike of the formation. The meta-conglomerates are always associated with thick quartzite beds.

Another bed occurs near Durrwood meadows (T22S, R33E, sec. 30). Here the bed is thin, and is sandwiched in between thick beds of massive white quartzite; the elongation of the pebbles parallels the structure of the beds. At this point the beds strike N50°W, dipping NE at 80°.

Quartzite.

Quartzite is the most important rock type in the Kernville series. Nowhere within the Sierra Nevada, as far as the writer is aware, has there been found thicknesses comparable to those in the Kernville region.

An important area of quartzite is the one outcropping prominently in the gorge of upper Trout creek. As one traverses the gorge, one passes across the strike of massive, white, crystalline quartzite beds for at least three miles. Another area of pure, thick, gray quartzite, is that of Cherry hill, where an important section about five miles long and from one-quarter to one-half mile wide is present.

Elsewhere the quartzite is usually well banded, with marked residual stratification. Quartzite layers, intercalated with other metamorphic types, are present in thick beds within the larger areas of the Kernville series.

In the large Mine area of the Kernville series are found several thousand feet of less pure quartzite. These are more thinly bedded than those of the other units. Occasionally quartzite is intercalated with thin marble lenses. These leach readily, and are indicated by their negative relief, where the soluble calcareous material has been removed.

Phyllites and Mica Schists.

Schistose rocks are present in limited amounts in the metamorphic units. In the larger areas, phyllites usually occupy a major part of the series. The phyllites are massive, of uniform grain, generally very dark in color, with well defined cleavage. Typical exposures occur in the large Mine area (T23S, R36E, secs. 26, 33, 34, 35), in the large areas of the metamorphic series up and down the Main Fork of the Kern, and in the Woodpecker unit (T22S, R34E, sec. 22).

Mica schists are important only in the Mine unit (T23S, R36E), and in Durrwood unit (T22S, R33E). In both of these, fine-grained, well-foliated, quartz-muscovite-biotite-garnet schists, and quartz-mica schists occur in considerable quantity. They seldom make up more than fifteen per cent of the total. These types are light-colored, with higher muscovite than biotite content.

Marbles.

The marbles of the region are coarsely crystalline, white, and dolomitic. They never exceed fifty feet in thickness. Such beds are especially well developed in the valley of the Main Fork of the Kern. In general, presence of limestone-marble beds indicates the presence of varied rock types in the Kernville series. Marble beds commonly carry varying amounts of barite.

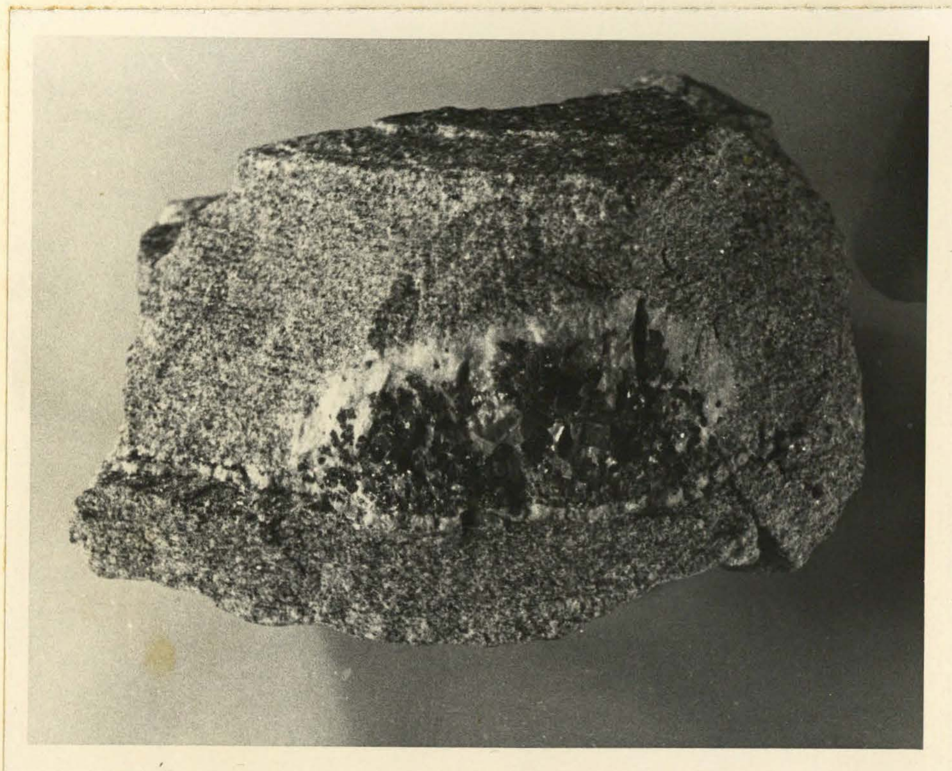
Silication of the marble often occurs near intrusive contacts. Marble beds generally thin along their strike and die out.

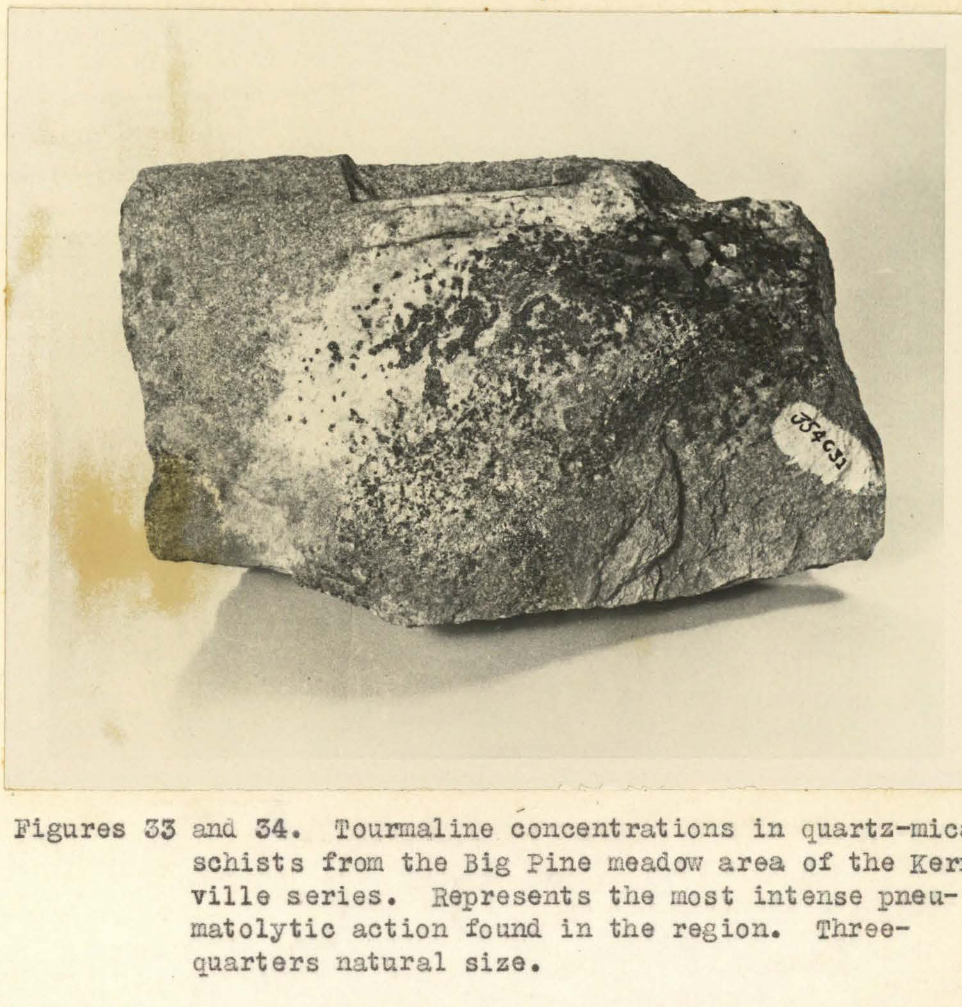
Meta-Volcanic Rocks.

In the Mine area there are several fifty-foot beds of metamorphosed volcanic rocks. These rocks make up a minor part of all the larger Kernville

Figure 31. Phyllite from the Fairview area of the Kernville series. Three-quarters natural size.

Figure 32. Typical outcrop of marble in the main valley of the Kern river. (T22S, R32E, sec. 30.)





Figures 33 and 34. Tourmaline concentrations in quartz-mica schists from the Big Pine meadow area of the Kernville series. Represents the most intense pneumatolytic action found in the region. Three-quarters natural size.

areas. They are usually light-colored, highly foliated, or massive, and of uniform composition.

Summary.

Following is a table indicating approximate percentages of rock types of the major metamorphic belts in the area, based on the thickness of the beds in each unit.

	Quartzite	Phyllite	Schist	Marble	Meta-volc.	Total
South Fork	95		2		3	100
Big Pine	95		2	3		100
Mine	45	20	25	5	5	100
Woodpecker	35	35	15	15		100
Durrwood	80		10	10		100
Cherry Hill	98	2				100
Burton Camp	98	2				100
Sirretta Pass	100					100
Fairview	25	25	25	25		100
Kernville	20	50	20	5	5	100

Percentage in All Areas.

Quartzite		65%
Phyllite		15%
Schists		10%
Marble		8%
Others		2%
	Total	100%

Plutonic Rocks.

Summit Gabbro.

Plutonic Rocks.

Summit Gabbro.

Areal Distribution.

The largest area of Summit gabbro lies on the summit of the eastern ridge of the Crestal Uplands physiographic division. It is named because of its summit position. Summit gabbro occupies the smallest area of any of the plutonic types. In the central part of the quadrangle large areas outcrop near the summit of Walker pass, where the gabbro is intimately mixed with the Sacatar diorite. The map should be studied to visualize the areal distribution of the Summit gabbro.

Megascopic Description.

The Summit gabbro is typically medium - to fine-grained, with occasional coarse-grained facies. The chief minerals visible in hand specimen are finely twinned plagioclase, of a bluish to greenish-gray color; varying percentages of hornblende; a little biotite; and considerable pyrite. Some parts seem nearly devoid of dark minerals; so much so that a fine-grained bluish-gray facies was labelled in the field "anorthosite". Microscopic examinations have shown, however, that the failure to correctly estimate the mafic proportions is due to the fineness of grain rather than to the lack of these constituents.

Microscopic Description.

The composition of the gabbro as determined in volume per cents from thin sections is as follows: labradorite to bytownite (An_{70} to An_{80}), 80%; hornblende, 18%, which is commonly altered to epidote; pyrite, 2%. Post-consolidation alteration is indicated by epidote, chlorite, and sericite,

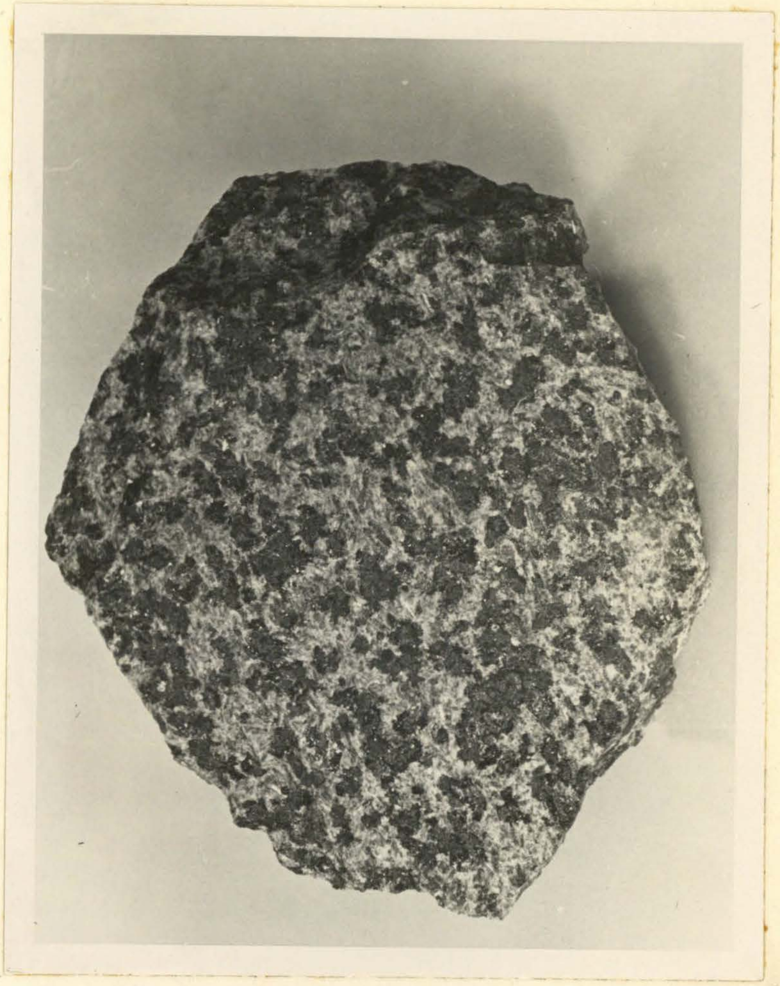


Figure 35. Typical biotite-rich phase of the Summit gabbro, from the gorge of Trout creek. Three-quarters natural size.

with some secondary calcite, and fine fracture-vein fillings of a mineral which is probably quartz. Alteration is usually prominent along grain boundaries. Pyrite, and the few grains of magnetite that are present appear secondary; they have surrounded other minerals. All minerals, especially the feldspars, show evidence of strain. Undulatory extinction is common. Bent cleavages in hornblende, although less common than pressure effects in the feldspars, are also found. The rock has hypidiomorphic texture, with cataclastic, and possibly pseudo-cataclastic texture effects. Mortar textures in certain grain combinations are found.

Sacatar Quartz-Diorite.

Sacatar Quartz-Diorite.

Areal Distribution.

The Sacatar quartz-diorite is named from the excellent exposures of the unit in Sacatar canyon. The northeastern part of the quadrangle is occupied almost entirely by the Sacatar and its facies. Between South Fork canyon and Main Fork of the Kern, no quartz-diorite of the Sacatar canyon unit is present; one or two small areas in the valley of the Main Fork of the Kern may be related to the Sacatar unit.

Megascopic Description.

In hand specimen the quartz-diorite is a melanocratic rock of medium - to fine-grain, with equigranular texture. Inspection shows a light-colored feldspar on which occasional twinning lines may be seen, abundant hornblende, some biotite, and an occasional grain of magnetite. Porphyritic facies are absent.

Microscopic Description.

Examination of thin sections of the quartz-diorite shows the composition of the Sacatar series to vary from an hornblende-diorite and biotite-hornblende-quartz-diorite, to microcline-quartz-diorite[1]. The unit averages quartz-diorite, with hornblende predominating over biotite, although occasionally the reverse is true. An average volume percentage composition is as follows: andesine (An_{40}), 68; quartz, 12, orthoclase or microcline or both, 5; hornblende, 10; biotite, 3; apatite, sphene, magnetite, and ilmenite, 2. Alteration is generally moderate, with leucoxene on both the

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1 Some writers prefer special names for such unusual rock types. The writer prefers a common term, with the mineral names of dominant constituents as adjectival prefixes.

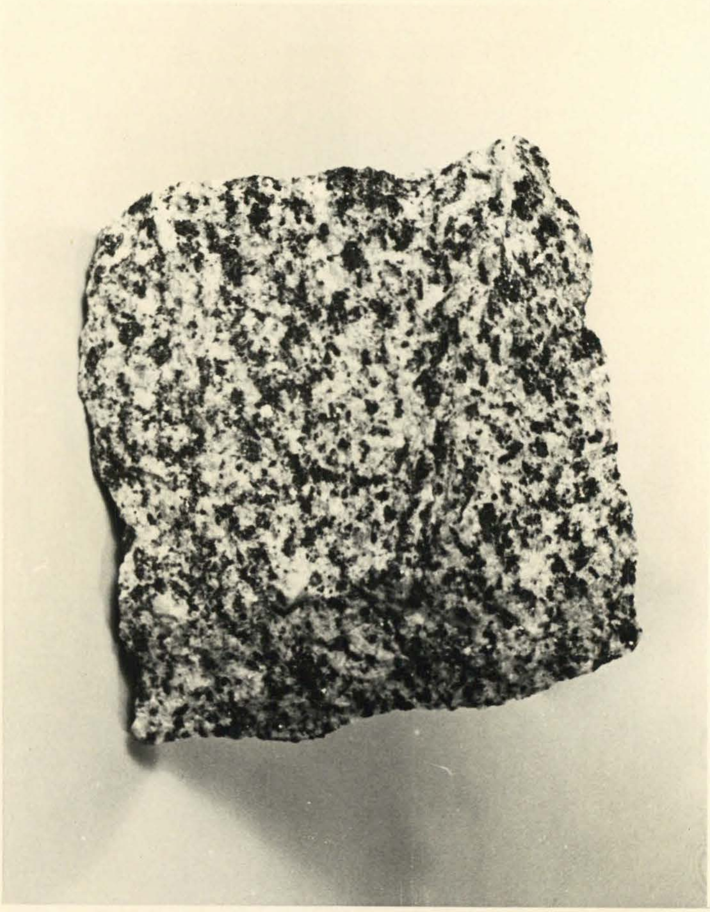


Figure 36. Typical quartz-diorite of the Sacatar unit. From the head of Sacatar canyon. Three-quarters natural size.

ilmenite and sphene; epidote and sericite (on the andesine); a little kaolinite (on potash feldspars); and occasionally oxides of iron. There is some textural indication of the secondary introduction of sphene. The andesine is sometimes zoned; in such cases selective alteration, with more intense core alteration is common. The quartz is usually filled with myriads of small needles that seem under the highest magnification to be apatite. The average apatites found in the rock are, however, long needles which cross grain boundaries, and which are generally bent. Sphene often fills the interstices between biotite grains. Magnetite commonly fills small fractures in the andesine.

The texture of the typical quartz-diorite is hypidiomorphic, inequigranular, but not megascopically porphyritic. Plagioclase is subhedral to euhedral. In some cases intense pseudo-cataclastic and cataclastic textures are developed. Other indications of late stage alteration is noted in the development of intergrowths, generally myrmekitic, but in some cases graphic. Strain is shown by bent twinning lamellae of the plagioclase, bent biotite cleavages, undulatory extinction in all the felsic constituents, and broken and bent apatite needles where they cross grain boundaries. Pressure effects seem more pronounced in this unit than in any other of the plutonic suites.

Following are sample volume percentage compositions of some of the rocks of the Sacatar unit:

No. 346B42 Biotite-hornblende diorite.

Andesine (An_{40})	65%
Hornblende	20
Biotite	8
Orthoclase	5
Apatite	2
Total	100%

No. 376137 Hornblende-biotite-quartz-diorite.

Andesine (An_{40})	65%
Quartz	10
Orthoclase	5
Biotite	10
Hornblende	8
Apatite	
Sphene	
Magnetite	2
	100%

No. 33B42 Biotite-microcline-quartz-diorite.

Andesine (An_{40})	52%
Microcline	26
Quartz	10
Biotite	7
Hornblende	3
Sphene	
Apatite	2
	100%

No. 311A41 Granodiorite.

Andesine (An_{35})	60%
Quartz	20
Microcline	15
Biotite	3
Apatite	
Magnetite	2
	100%

The sample analyses given above indicate some of the variations of the Sacatar intrusive. The average composition is hornblende-quartz-diorite.

Facies of the Quartz-Diorite.

Gabbroic Facies: Certain parts of the quartz-diorite unit have megascopic characteristics which are similar to the Summit gabbro. Microscopic studies of these facies indicate the association with and similarity to the Sacatar diorite rather than with the Summit gabbro, although some evidence favors association with the latter, such as greater calcic content in the plagioclase, and decrease in the percentage of accessory minerals.

Indeed, the wisdom of attempting a separation of the diorite and Summit gabbro might be questioned, as they are undoubtedly closely associated in age and origin. However, there exists in the region a well-defined gabbroic unit, and a well-defined dioritic unit, with certain gabbroic facies closely similar to the Summit gabbro in the latter. The gabbroic facies of the Sacatar are found in very small areas, grading laterally into it. There is no evidence where such is the case, that the gabbro is any earlier or later than the quartz-diorite in which it occurs. On the other hand, where true Summit gabbro is adjacent; evidence is always fairly clear for the intrusive nature of the diorite into the gabbro. The gabbroic facies of quartz-diorite are commonly of finer grain than the normal Summit gabbro. Occasional porphyritic facies of the gabbroic variation are seen. Strong evidence in favor of the relations between Summit gabbro and the gabbroic facies of Sacatar diorite as outlined above lies in the fact that the Sacatar quartz-diorite is, in certain parts, highly contaminated with inclusions and schlieren that are interpreted by the writer as xenoliths from the Summit gabbro. In such cases, some of the gabbroic facies of the Sacatar also contain finer-grained inclusions of the older gabbro.

<u>Granodioritic Facies</u>: Certain phases of the Sacatar have the composition of granodiorite. As granodiorite is generally considered the average composition of the Jurassic Sierran batholith, and as there are wide areas of typical Sierran granodiorite in the region, the writer often experienced difficulty in differentiating these from the granodioritic facies of the Sacatar. In such cases, the determinations were made on field associations. After microscopic examination of the rocks of the region, it was found that one fact aided the differentiation. The Isabella (Sierran) granodiorite in this region tends on the average toward a true granite, with

quartz-monzonite to granodiorite facies. Thus in those granodioritic rocks closely associated with the Sacatar quartz-diorite, the quartz content is so much lower than in the Isabella intrusive that one can almost use the quartz content to differentiate these phases. The granodioritic phase of Sacatar quartz-diorite is somewhat finer-grained than is the Isabella granodiorite, and has a higher percentage of dark minerals, chiefly biotite.

Contaminated Diorite: In the northeastern part of the quadrangle are mapped areas of "Contaminated quartz-diorite". These areas contain an especially large number of inclusions of fine-grained gabbroic material. As seen in the accompanying photographs (Figures 37 & 38), these occur in countless thousands in the Sacatar quartz-diorite. They approximate the Summit gabbro in texture and composition.

Figure 37. Dark inclusions in Sacatar quartz-diorite.
Head of Sacatar canyon.

Figure 38. Sacatar quartz-diorite (coarse), with fine-grained inclusion. Near Kennedy meadows. Two-thirds natural size.

Isabella Granodiorite.

Isabella Granodiorite.

General Statement.

The Isabella granodiorite, varying to granite, quartz-monzonite, and quartz-diorite, was so named by Miller (1931, p. 344) from typical exposures near the town of Isabella. The Isabella unit covers about 60% of the area studied. Granitic facies are more common in the areas of detailed study, than at the type locality. The Meadowlands is composed almost entirely of the Isabella and its facies. Here, continuous areas of granitic rocks are interrupted only locally by small areas of the Kernville series, and occasional lava flows of variable character.

Megascopic Description.

Typical specimens of Isabella granodiorite are medium - to coarse-grained, leucocratic rocks. (Figure 39) Porphyritic textures are occasionally developed; phenocrysts, generally of a potash or finely twinned sodic feldspar, are of small size. Quartz is abundant in small anhedral grains. Very small grains of mafic constituents are present, usually biotite in almost invisible flakes. The general textures are allotriomorphic granular. Deep weathering of the Isabella unit makes the selection of hand specimens difficult.

Microscopic Description.

The average composition of the Isabella and all its facies is a quartz-monzonite. Typical granodiorites seem to be less frequent in their occurrence here than in any other part of the range. The average rock shows the following volume percentage composition: quartz, 30; orthoclase and/or microcline, 30; oligoclase-andesine (An_{30}-An_{40}), 30%. Accessory minerals

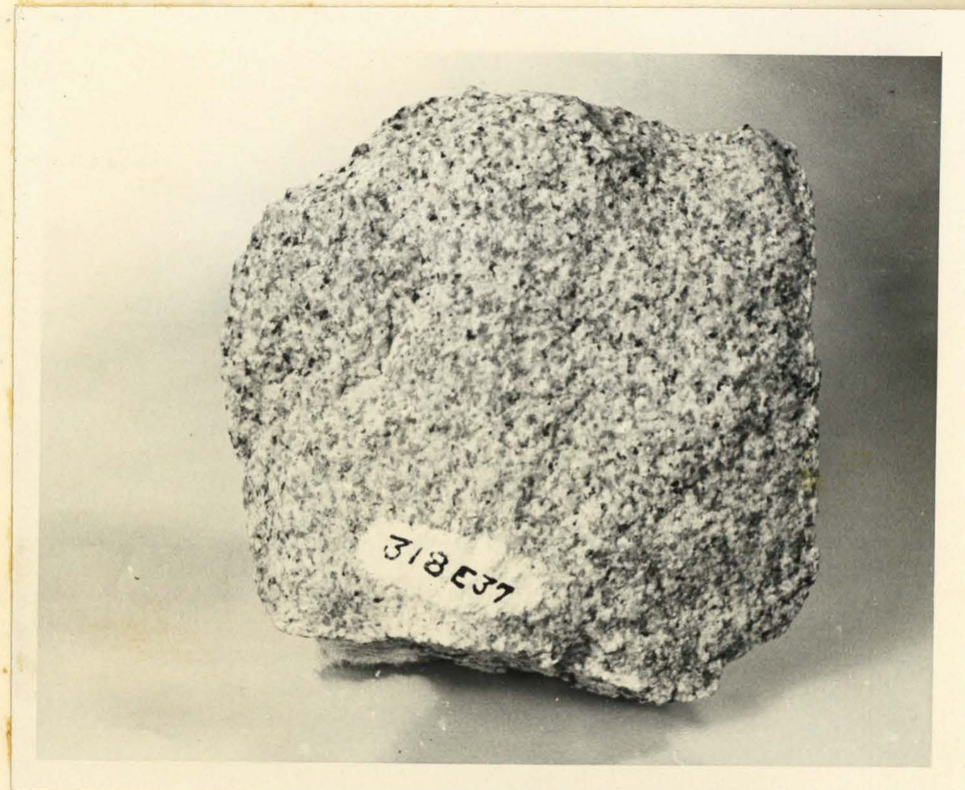


Figure 39. Typical Isabella granodiorite. Note the uniform medium grain. Near Big Pine meadow. Two-thirds natural size.

vary from 0 to 10 per cent, usually considerably less than the latter. Common accessory and varietal minerals are biotite, hornblende, muscovite, apatite, epidote, sphene, and magnetite. Kaolinite, sericite, hematite, and a little chlorite are commonly found. Sphene is found in large quantities in some facies. The quartz contains myriads of fine, small needles of bluish apatite. Undulatory extinction is common only in the quartz. The plagioclase is zoned, with the more calcic cores altering to epidote, with unaltered sodic parts.

The following are volume percentage compositions of some typical rocks of the Isabella unit:

No. 11A12 — Alaskite.

Orthoclase (perthitic)	60%
Quartz	35
Oligoclase-Andesine (An_{32})	4
Biotite	
Magnetite	1
	100%

No. 51L25 — Alaskite.

Quartz	45%
Orthoclase	35
Oligoclase-Andesine (An_{30})	15
Microcline	4
Hornblende (2 grains)	
Muscovite (1 grain)	
Magnetite (1 grain)	1
	100%

No. 813Y20 — Quartz-monzonite.

Orthoclase and microcline	40%
Oligoclase-Andesine (An_{30})	40
Quartz	15
Biotite	
Muscovite	
Apatite	
Magnetite	5
	100%

No. 814X20 Quartz-monzonite.

Orthoclase and microcline	33%
Andesine (An_{40})	33
Quartz	27
Biotite	3
Hornblende	3
Apatite	1
	100%

No. 371G35 Granodiorite=Quartz-diorite=Tonalite.

Andesine (An_{35})	70%
Quartz	25
Orthoclase	3
Biotite	
Magnetite	
Apatite	2
	100%

Facies of the Isabella Unit.

The general character and composition of the rocks of the granitic portion of the Isabella unit have been described. There are, however, certain other facies which have been differentiated in mapping. Such variations have been indicated wherever the writer felt that they were mappable units.

Dioritic Facies: In certain areas, especially along the Main Fork of the Kern river and in the Bartolas flats, specimens selected at random cannot be distinguished from the Sacatar quartz-diorite. In such cases, one must resort to field association and relations to separate these diorites from the Sacatar. The separation of these dioritic facies seemed at first impossible, and the more complicated relations appeared in the areas first undertaken for detailed study. On the geologic map two areas of diorite that are a part of the Isabella unit are mapped; they lie in the main valley of the Kern river.

Granitic Facies (Foliated): A facies of the Isabella that is commonly encountered with random relationships (though commonly marginal) to the parent mass is a coarse foliated granite, in which large anhedral quartz crystals alternate in coarse bands with potash and soda feldspars in a highly foliated, leucocratic, equigranular rock having the composition of a granite. It was found impractical to attempt to map this phase separately. The distinct linear parallelism of the minerals is beautifully shown in hand specimen; it is crudely shown in thin section. Rocks of this type are commonly alaskites.

Pegmatitic Facies: Mappable units of pegmatitic granite, composed of coarse graphic intergrowths of quartz, orthoclase and microcline, in large masses, occur in the central part of the Meadowlands province. The Church domes, eminences prominently visible from Manter and Taylor meadows (plate XVI) are composed of this phase. Pneumatolytic minerals such as muscovite, tourmaline, and others are absent.

Porphyritic Facies: In several occurrences, indicated on the map, areas of moderate grained Isabella are locally filled with numerous crystals of orthoclase, individual and twinned (Karlsbad), which vary from a fraction of an inch to one and one-half inches in size. They are non-uniform in composition, composed of quartz, orthoclase, and biotite.

Contaminated Facies: A large area in the central part of the Meadowlands province has been mapped as 'contaminated granodiorite'. By studying the map accompanying this report, it is seen that the area encloses many inclusions of the Kernville series. The contaminated facies is not one in which a great deal of assimilation has taken place, changing the composition of the invading rock, but rather one in which myriads of inclusions of the Kernville series and the Sacatar(?) quartz-diorite have been enveloped.

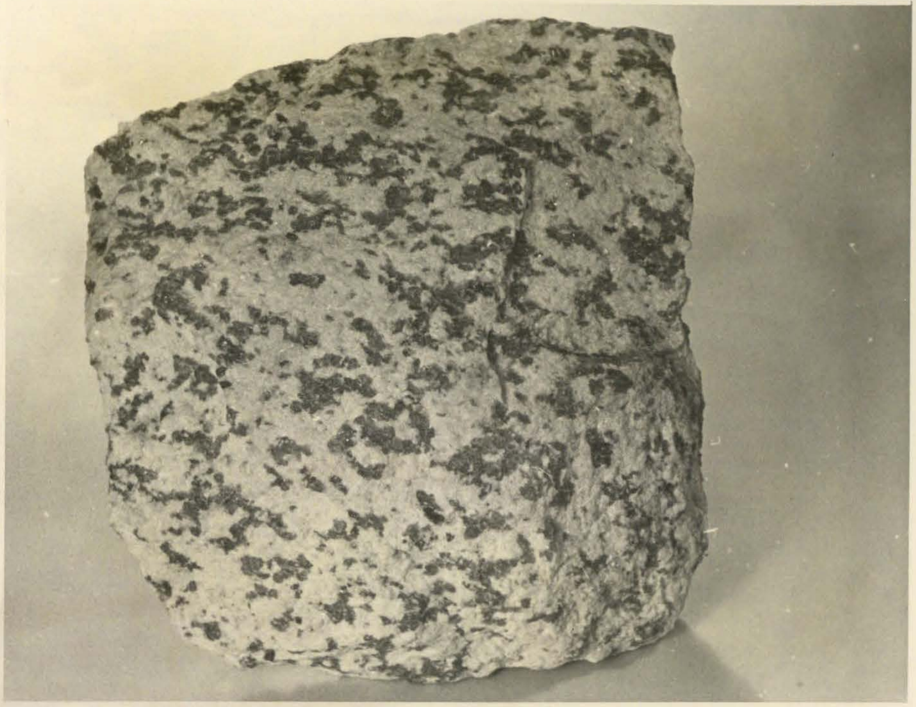


Figure 40. Granitic facies of Isabella unit. Foliation less marked in photograph than in the field. Three-quarters natural size. Sirretta pass.

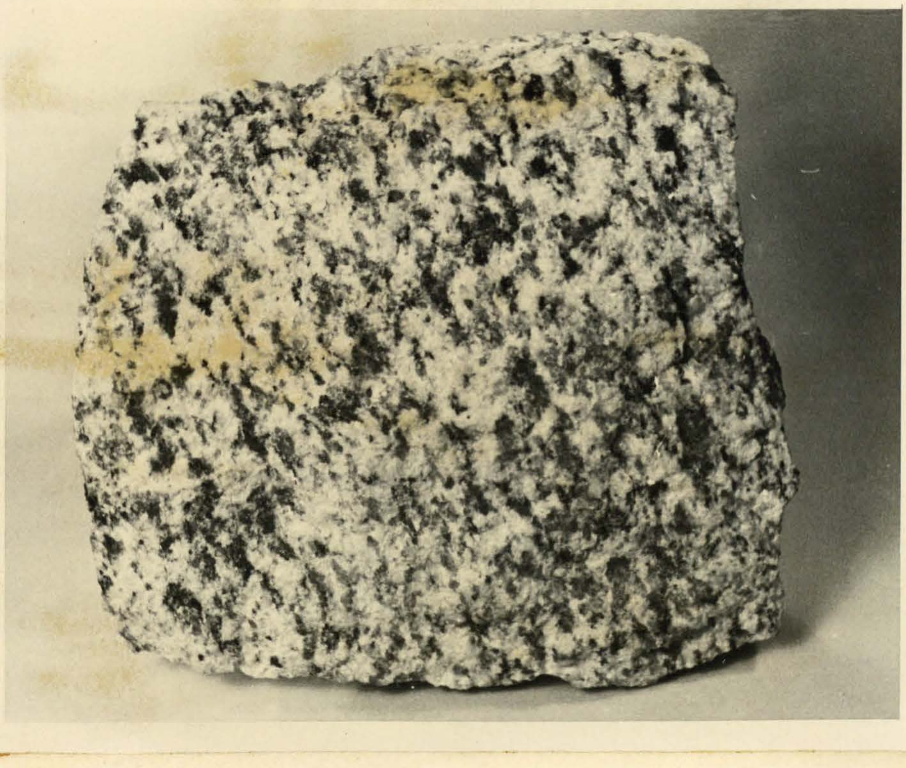


Figure 41. Granitic facies of Isabella granodiorite. Highly weathered. Near Round meadow. Three-quarters natural size.

Figure 42. Coarsely foliated phase of Isabella granodiorite. This has the composition of a granite. Near Big meadow. Three-quarters natural size.

Figure 43. An unusual porphyritic phase of the Isabella unit. Orthoclase phenocrysts are present. Durrwood meadows. Three-quarters natural size.

In such cases, many areas of very pure granodiorite occur; but so many small inclusions exist, which are not mappable units, that the only solution seemed to be to map the whole area as a separate unit. In the area of the contaminated phase, zones of gneisses are developed as border phases of the granodiorite marginal to the Kernville series. (Plate XVII.) These are diagramatically indicated as mappable units.

Hypabyssal Rocks.

Hypabyssal Rocks.

Lamprophyre Dikes: Lamprophyre dikes are rare. A few of pyroxenitic character cut the Sacatar diorite in places along Sacatar canyon. They were not found in any other formation, not even the gabbro; thus their relations in time are in doubt.

Granodiorite Dikes: Large Isabella granodiorite dikes cut the Sacatar quartz-diorite in a number of places. These dikes are commonly in groups, in which they are strikingly parallel to one another. The dikes have low dip angles. They may be traced directly into the parent mass.

Aplite Dikes: Aplite dikes cut all of the formations except the lavas and the gravels. They are extensively developed in the Isabella. They are found near the contacts of the older rocks, especially the Sacatar quartz-diorite, and in cross-cutting relations to the Kernville series.

Pegmatite Dikes: Several large pegmatite dikes occur within the area. The largest one, located near the head of Chimney meadows, is composed of almost pure potash feldspar and milky-white quartz. Being a very large dike, about thirty feet wide, it has been opened up as a silica mine. Giant-grained texture is common. Several other such dikes occur in the Domelands, and the lower Bartolas country. All have been prospected. The larger ones occur in Isabella granodiorite. Some smaller pegmatites occur in the Sacatar quartz-diorite. These have in some cases tourmaline and biotite, in addition to the usual felsic constituents.

Silexite Dikes and Veins: Silexite dikes occur in a few places in the Domelands, where the Isabella is uniform in texture and composition. They contain a few crystals of potash feldspar, in addition to the quartz. Some quartz veins are also found.

Interpretive Section.

Discussion of Problems of Special Importance in the History of the Crystalline Complex.

Discussion of Problems of Special Importance in the History of the Crystalline Complex.

Summary of Relations between the Crystalline Units.

The oldest unit in the area is the Kernville series, into which all later units were intruded. Evidence is seen in numerous places where cross-cutting relations are found.

The Summit gabbro is the first of the major plutonic units to cut the Kernville series, followed by the Sacatar quartz-diorite. Evidence for these relations are: (1) cross-cutting dikes of quartz-diorite in gabbro (2) xenoliths of Summit gabbro in the Sacatar quartz-diorite. The final emplacement brought in the Isabella granodiorite and its facies, which cuts all the other crystalline units.

Attitude of the Kernville Series during and before Intrusion.

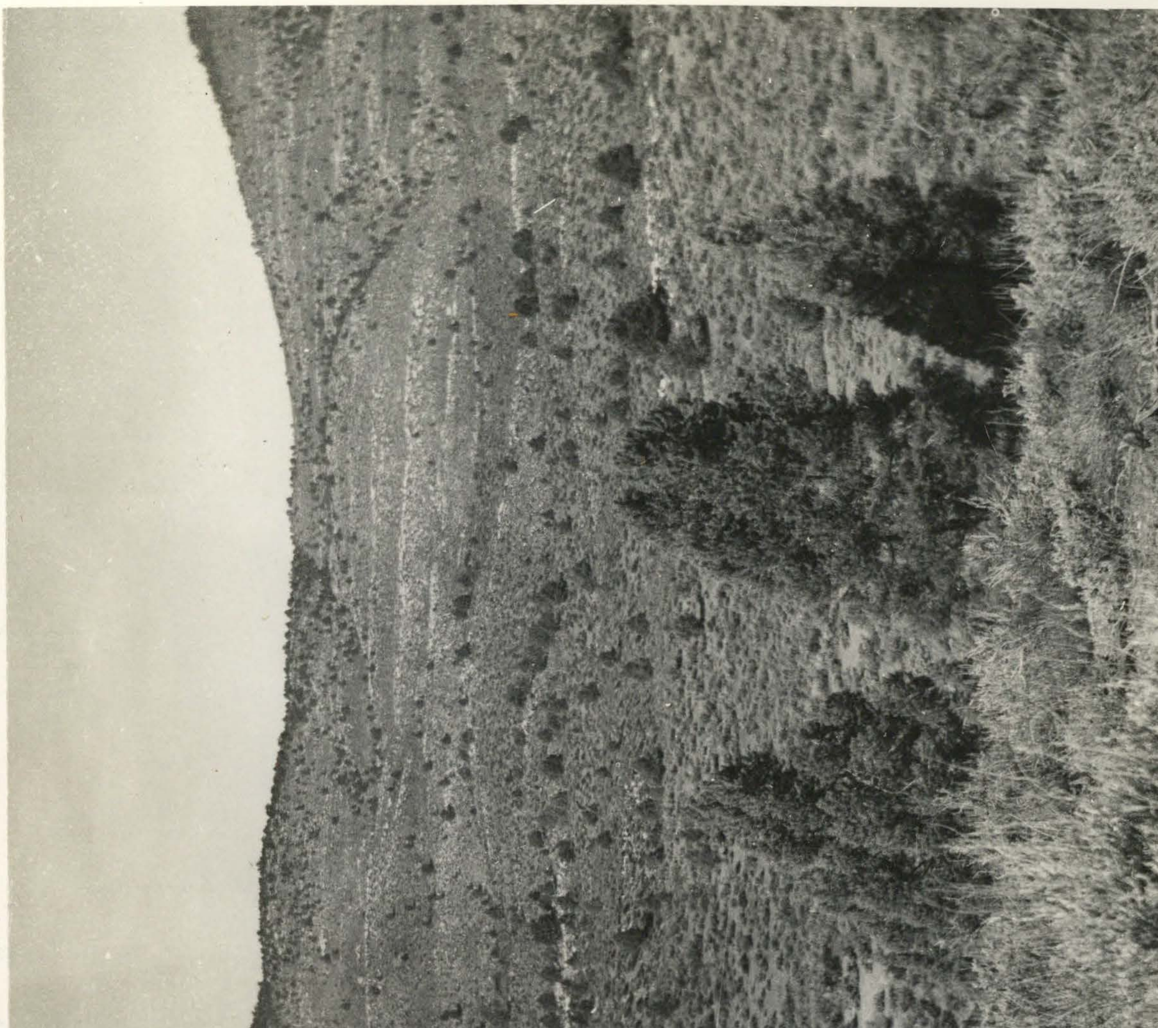
There has been considerable discussion in the literature as to the attitude of the meta-sedimentary rocks of the Sierra Nevada before the intrusion of the batholiths that have invaded the region. Where two meta-sedimentary units are found together it has been shown definitely that the older (Calaveras) is more highly metamorphosed and folded than the younger (Mariposa) unit. In the Kernville region, it has been shown that only one meta-sedimentary unit is present. This would seemingly simplify the problem; it seems, however, that it has served to make fewer facts available.

It has been pointed out by Knopf and Thelen (1905) that:

> "The relatively greater uplift of the southern portion of the Sierra Nevada has long been recognized, and Le Conte has pointed out that the intensification of the erosive activities produced thereby, has effected an

Plate XII.

Intrusive relations between Sacatar quartz-diorite and Isabella granodiorite, showing Isabella dikes cross-cutting quartz-diorite. Looking west from south end of Long valley. East of White dome flows on right. Notice the marked parallelism of the dikes.



> almost complete denudation of the irruptive granites. In the High Sierras a few small detached areas and narrow belts of schistified rocks are all that remain of the extensive roof under which the plutonic magmas cooled."

Other workers have pointed to the same fact, and have shown that evidence of the attitudes of these old rocks is fragmentary; deductions based on a small number of facts is all that the geologist has with which to work.

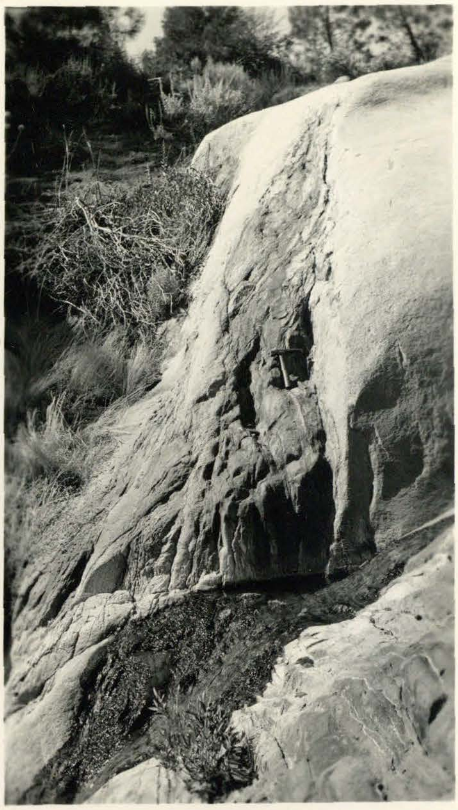
The situation in the Kernville region is similar to that in other parts of the Sierra Nevada. There are only one or two large areas in which key beds might be found. In these, however, key beds were absent. Most of the remnants are so shaped, like septa, that their thickness is measured in hundreds of feet and their length in several miles.

Within the area, however, a moderate degree of deformation before intrusion of the diorite-gabbro of the Sacatar-Summit units is indicated. So firmly established was the structure of these beds before the emplacement of the intrusives, that the beds shaped the structure of the intrusive units, rather than having their structures changed by the pressures accompanying the batholiths.

W. J. Miller, in his paper on the southern Sierra Nevada (1931) offers the following evidence in favor of the highly folded character of the Kernville series before the intrusion of the batholithic units: (1) The bedding and foliation of the Kernville series are parallel. (2) The dips of the beds are all fairly steep. (3) The strike of almost all units of the Kernville series is uniform. (4) The granodiorite and other rocks which invaded the Kernville series is massive, except locally along margins adjacent to the Kernville series. (5) Local metamorphism of phyllitic rocks to mica schists occurs only along contacts.

Following are a few comments on the above points: (1) The strike and dip of the major areas vary from N15°W to N35°W, with few easterly strikes. The dips are seldom less than 85°. As pointed out by Miller, persistent attitudes (especially in septal-like masses) indicate development of the present attitudes well before intrusion. (2) It is notable that small masses adjacent to large areas of the Kernville series (such as in the Brush creek drainage where quartzite inclusions detached from the main mass (figures 44 & 45), have dimensions twenty feet long, by two feet wide, by x feet deep) maintain the attitude of the parent mass even when several hundred feet to one-quarter mile or more away. Control of intrusive by wall rock is indicated by such small inclusions of host rock in which attitudes correspond to those of the parent masses. (3) Crude foliation within the granodiorite, generally shown by coarse, gray, quartz grains, is, as Miller points out, confined more or less to the margins of the granodiorite areas. Such facies are commonly granitic. (4) Miller's fifth point has been verified in the region of his study. Phyllitic rocks along contacts are absent in the Kernville series in the region of the writer's study. Impure quartzites commonly constitute the wall rocks. In such cases, however, contact gneissic phases are developed from the parent mass of meta-sediments for distances of from one-quarter to one-half mile. These areas are diagrammatically indicated on the geologic map. The writer interprets these gneisses as foliated border zones, formed by siliceous magma, which has incorporated some of the Kernville series, making a hybrid more siliceous than the granodiorite, in which foliation is pronounced.

In addition to the points made by Miller, it seems that support for the hypothesis requiring deformation before or during intrusion is offered by: (1) Cross-cutting relations are lacking between intrusive and wall rock.



Figures 44 and 45.

Inclusions of the Kernville series in Isabella granodiorite, on Brush creek, near Burton camp. Attitudes within the inclusions parallel those of the parent mass, about one-quarter mile to the east.

Figure 44.

Figure 45.

There is even some evidence to suggest that the magma followed the surface of one of the beds of quartzite and, using this surface as a gliding plane, migrated upward, controlled by this plane. (2) Erwin (1934, p. 56) describes thrust planes in the metamorphic rocks of the central Sierra which he says may be attributed to the thrusting action of the granodioritic intrusion upon its rise into the crust. Careful search in the Kernville region has failed to reveal any thrust planes in the Kernville series. This, although negative evidence, indicates lack of force on the part of the magma during invasion, and thus, pre-intrusive deformation.

Thus, the evidence seems to indicate intense and possibly complete deformation of the Kernvile series, at least by the time of consolidation of the compound granitic batholith. The lack of extreme foliation in the gabbro-diorite of this region as compared with other mafic intrusives in the Sierra even suggests that the attitudes of the Kernville series were established before the invasion of the gabbro and quartz-diorite intrusives.

Intense folding of metamorphic rocks has been suggested by other workers. Literature has been cited bearing this out in the area of study. Matthes (1933, p. 33) says:

> "At least two ancient mountain systems must have in turn occupied the place on which the present Sierra fault block stands. This fact is evident from the structure of the metamorphic rocks; the first mountain system, which was presumably of Appalachian type, is indicated in the complexly folded strata of the Calaveras formation; the second mountain system, more clearly of Appalachian type, is indicated in the simpler, northwestward-trending folds of the Mariposa slate. [Absent in the Kernville region either because it was never deposited or because it has been eroded away.] . . . . it was under and into the folds of this system that the magmas of the compound batholith were intruded."

Mayo (1935, p. 680) believes that the meta-sediments to the north, which he has shown to be Devonian (Mayo, 1931) were highly folded before the rise of the Sierran batholith.

Relations of Intrusives and Wall Rocks.

An extremely interesting paper appeared recently in the Journal of Geology (Mayo, 1935), in which was discussed "Some Intrusions and their Wall Rocks in the Sierra Nevada." The area covered by this paper lies about 150 miles north of the Kernville region, near Convict lake, north of Bishop, California. Because of the fact that there are marked comparisons between the conditions there, and in the Kernville region, it seems well to review some of Mayo's data, and to show how the Kernville region differs therefrom or is similar thereto. The work of Mayo was based mainly on the method of analysis of batholithic masses employed by Cloos and Balk and others.

The septal character of the invaded rocks throughout the Kernville region has already been mentioned. Similar features are noted by Mayo (1935, p. 676), who further calls attention to the elongate character of granitic rock masses separating the septa of the older rocks. The geologic map presented by Knopf (1918) also shows septa of the older rocks in the region intervening between that of Mayo and of the writer. The significant difference between those masses described by other workers and those of the Kernville region lies in the composition of the rocks comprising them. In the regions to the north, such septa are little different in composition from other inclusions associated with them which lack the septal shape. In the Kernville area, those masses of septal shape are always composed of one rock type, quartzite, and its variants. Such septa always stand nearly vertical, with what seem to be vertical contacts. Invaded rocks found in the gabbro-diorite never have the septal shape. In no place could there be observed vertical distances through which the downward extent of the septa could be seen, such as was found by Knopf and Thelen (1906), Erwin (1934), and Mayo (1935) in adjacent areas. The attitude of the contact with intrusive agrees closely with those described by Mayo, but the writer found no exceptions to the rule of high angle contacts, as did Mayo (1935, p. 681).

The septal inclusions are always associated with the Isabella granodiorite. Inclusions of the Kernville series found in the gabbro-diorite generally show high angle contacts with intrusives, although exceptions to this rule have been noted in certain cases. Most of the areas of the Kernville series involved in the gabbro-diorite are either wider than those of the granodiorite, or they have less linear persistence, and thus are not classed as septa.

Mode of Emplacement.

Some Hypotheses.

Zones of Weakness.

Every effort was made to determine the reason for selection by the invading rock of the areas now occupied, and to discover zones up which original passage of the magma might take place. The fact that the remnants of the older rocks are so small by comparison to the volume of granodiorite makes the problem difficult. So much area is occupied by granitic rocks and so little by the Kernville series that zones of weakness cannot be shown ever to have existed. No zones of particular weakness have been found within the areas of the Kernville series now preserved.

Assimilation and Stoping.

It is suggested that granitic rocks occupy particular areas because of the uniform composition of the invaded rock residuals. Being all quartzite, and thus highly siliceous, it seems that the invaded rock would resist attack by a siliceous magma. Thus assimilation of the more argillaceous and calcareous members of the series might permit the residual members to be quartzitic. If such is the case, the channelways of migration for the magma were made by assimilation of zones favorable toward reaction with the magma.

An effort to check this hypothesis was made in the course of field work. Several valid objections were at once apparent. (1) It seems unlikely that all of the material of composition other than quartzite would be assimilated. (2) The quantity of material involved, if one can judge by the quantities present elsewhere in the series, would make it inevitable that the magma would show strong evidence of introduction of material of new composition. The writer made careful petrographic analyses of rocks adjacent to well-exposed contacts with the quartzite inclusions. In one particularly typical and well-exposed place it was found that at a sharp contact (these contacts are always sharp), over a distance of less than 200 yards, the granodiorite adjacent to the contact changed composition only by the increase in the precentage of sphene in the rock. The normal facies 200 yards away carried one-half to one per cent sphene; varying progressively in size and amount, becoming coarser toward the contact, the sphene increased to as high as eight per cent. (Figure 72) Otherwise, evidence for the introduction of material was lacking. Further, where detached masses of the invaded rock occur, no composition changes are observed in the intrusive, even where small masses are rather widely separated from the main inclusion. Furthermore,

Figure 46. Granodiorite of the Isabella unit, from Cherry hill. Taken from the west contact with the quartzite of Cherry hill metamorphic area. Sphene percentage in the specimen above is about eight per cent. Sphene is outlined in the specimen.

petrographic analyses of numerous slides of specimens from widely separated parts of the Isabella unit shows that the rock is essentially the same in composition whether adjacent to or separated from remnants of the Kernville series. Thus, even though a thick mass of uniform rock, formerly part of the Kernville series, might have been assimilated, the resultant product should show compositional differences from specimens of the same unit in widely separated areas. The assimilation hypothesis is, therefore, not supported by the observed facts.

Crowding by Force.

A third hypothesis examined was that the magma in its rise crowded out of the way the less resistant (argillaceous) rocks, forcing them upward in front of the magma, toward the roof. Thus, of course, they would at the present time have been eroded away. This hypothesis is hard to check because most evidence would be removed by erosion. Also, such action would produce extreme thrusting and evidence of compressive force in the rocks remaining after emplacement. It has already been indicated that no such evidence is present.

Emplacement in Kernville and Adjacent Regions.

Mayo (1935) finds support for the theory that the magma rose under great pressure in the region to the north, where he presents adequate evidence to show that crushing effects were severe on the invaded rocks. However, he believes that the invaded rocks were almost completely deformed before the invasion of the batholith. He says (1935, p. 687):

> "Since the intrusions were forcefully emplaced, it seems reasonable to suppose that during the period of folding the magma was driven upward by orogenic pressure . . . . (and) that the magma rose after folding was essentially completed."

Evidence for this consists of a statement regarding the relative age of the bedding and schistocity in the older rocks, which, he points out, are roughly moulded to the outlines of the intrusions. When the intrusive traverses the bedding, it also traverses the schistocity. Thus, Mayo believes the structure to have been essentially in place before intrusion. Secondly, Mayo points out that flow lines in the magma coincide with contacts, and that internal structures are lacking (almost) in the batholithic rock. He interprets this as indicating absence of lateral compression, inasmuch as the invading mass transgresses regional trends and parallels contacts.

The writer has found the above points to be true in the southern Sierra, Kernville region. He fails, however, to find evidence of thrusting in the rocks invaded. However, it has been shown that erosion of the southern Sierra has been much deeper than in other parts of the range. Thus, it might be expected that such small remnants of wall rocks in what was during intrusion, a central or lower part of the intrusion chamber, might fail to show evidence of thrusting action, and that the magma may have advanced under pressure here, as well as to the north.

The paucity of evidence regarding mode of emplacement is probably explained by the greater depth of erosion in the Kernville region than to the north. To quote again from Mayo (1935, p. 680), he says:

> "Erwin's suggestion (1934, p. 19) that the area around Mount Ritter is a remnant of the irregular roof of the central massif can only mean that in this region erosion has not exposed a very low level in the intrusive. This suggestion is supported by the nature of the metamorphism of the wall rocks. In general, the thermal metamorphism has been of low grade . . . . but cataclastic effects are intense and widespread. With local exceptions, restricted to the immediate vicinity of igneous contacts, the marbles appear

> to have been the only rocks to yield mainly by recrystallization. It is evident, therefore, that the surface now exposed represents a relatively high level, where adjustment took place mainly by crushing and shear. Since so little of the roof is preserved . . . . this level must be appreciably deeper than the surface now revealed in the Boulder batholith, Montana (Grout and Balk,[1] 1934)."

The fact that cataclastic textures and general evidence of compression is lacking in the Kernville series where observed by the writer, plus the fact that thermal effects appear to be more prominent in the Kernville region than in others, (although the abundance of quartzite makes such a statement hard to prove) suggests a distinctly deeper level in the batholith than to the north.

Furthermore, the writer feels that the rocks of the Kernville series within the main canyon of the Kern, and those of the high Meadowlands-Crestal Uplands province, represent the same series at different erosional levels, the rocks of the main fork of the Kern obviously being, as pointed out by Lawson (1906, p. 406), part of a sunken block. That the rocks of these two levels are the same is indicated by their similar lithologic character. If there were at the present time relationships to be discovered between large batholithic masses and the Kernville series, within the main canyon of the Kern, then the theory advanced by Mayo that the magmas contributed active thrust might receive support in the Kernville region.

Summary.

From evidence presented, it seems that the magma entered rocks already intensely deformed, and that such deforming force had practically subsided at the time of intrusion. At the level of erosion represented in the Kernville region, active thrust on the part of the magma during intrusion

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[1] Internal Structures in the Boulder Batholith. Geol. Soc. Amer. Bull., Vol. 45, pp. 877-896, 1934.

is not indicated. A quiet invasion, under hydrostatic, rather than orogenic pressure, is evidenced by the elongate, non-ruptured septal-like inclusions of the Kernville series. At a higher level in the batholith, such as is found northward, activation of the magma under intense pressure is definitely shown. In all probability, similar features to those found in the Kernville area would be found to the north at a comparable depth.

Active thrust during emplacement, at high levels, with decreasing effective pressure downward in the advancing magma, is indicated by the above evidence.

Remnants of the Kernville Series. Xenoliths versus Roof Pendants?

Introduction.

In considering the origin of large inclusions found in most batholiths it is important to determine the nature of the residual blocks of invaded rock. Such determinations often permit inferences regarding the depth of erosion, the attitudes of the host rock before intrusion, and the movements of the magma and the invaded rock at the time of emplacement. Daly (1906, p. 336) proposed the term "roof pendant" for those residual masses of invaded rock attached to the host rock at the time of consolidation of the intrusion. Erosion, of course, may disconnect such masses from the parent. In such cases Daly (1933, p. 122) points out that:

> ". . . . any direct evidence for connection with the rest of the roof is lost. That they were originally parts of the continuous roof may, as a rule be inferred if the pendants are of large size and in ground plan have major axes faithfully parallel with the average strike of the rocks around the batholith. This criterion is likely to distinguish pendants from mere inclusions, that is, blocks that had been completely immersed in molten magma."

Status of the Problem.

The terms 'xenolith' and'roof pendant' seem to be rather loosely used in the literature. Most writers use the word 'inclusion' to introduce the discussion of fragments of invaded rock, and then proceed to refer to them as xenoliths or roof pendants without presenting evidence for their conclusions regarding them. The reader is thus left to decide for himself the basis on which the conclusion was reached. The result is that few criteria have been presented for the discrimination of the two forms since 'roof pendant' was defined by Daly.

Criteria for the Recognition of Roof Pendants.

Parallelism in Plan of Residual Areas of Invaded Rock: The residual units of the Kernville series are more or less elongate in plan, parallel to the elongation of the Sierra, and generally parallel to the older rocks of the west side of the central Sierra Nevada. That roof pendants show this general characteristic was indicated by Daly in his original definition.

Parallelism of Structure within Residual Areas to Regional Elongation: In the Kernville area the attitudes of beds is accordant with the elongation of the inclusion in every case. This coincidence is particularly striking where long, narrow residuals are studied. It is thought that this would not be true were the masses xenolithic; cross-cutting relations of intrusive and wall rock would normally be expected if the mass were detached during or before consolidation.

Shape of the Residual Masses: Numerous bodies of invaded rock are septal in shape, having very great longitudinal dimensions and very narrow widths. In the Durrwood meadows area of the Meadowlands province, one septum is six miles long and about one-eighth mile wide. Another one outcrops at the base of Sirretta peak. It has a length of three miles and a width of less than 500 feet. Other septal-like inclusions are described by Knopf (1918, p. 62) and by Mayo (1935, p. 676), in areas to the north. In such cases, detachment before consolidation would probably cause rupture of the septa, since they are so thin. Rotation of blocks thus broken would be expected by forces in the invading rock. It is believed that shape may aid the determination of an inclusion as a roof pendant. If septa are not ruptured a quiet plutonic invasion under hydrostatic rather than orogenic pressure would be indicated.

Host Rock Controls Structure of Invading Mass: Where inclusions control the development of internal structure in the intrusive, great rigidity for the host is indicated. Such strength in inclusions suggests their connection with the parent mass; it seems probable, were the inclusions detached, that the blocks would be rotated and internal structures in the intrusive would develop by local forces in the magma, rather than be parallel to regional trends in the wall rocks. Internal structures in the granodiorites of the region are absent except adjacent to residuals of the Kernville series. In such cases, flow lines accord with the attitudes of the residuals, oftentimes, for distances from one-half to three-quarters of a mile into the intrusive. Blocks of wall rock detached before consolidation would be incapable, except in rare cases, of controlling internal structure.

Residual Areas Composed of Rocks Resistant to Assimilation: According to data presented by Daly (1933, p. 299), areas composed of rocks of similar bulk composition to an intruding rock would be less readily assimilated by the intrusion than otherwise[1]. Thus the plane of a bed might form the line between readily incorporated material and material difficult to assimilate. Daly (1933, p. 299) has compiled reports on twenty-four cases of assimilation of quartzose rocks, and in only two of these were the older rocks invaded by siliceous intrusives. In only one instance was pure quartzite assimilated, and the intrusive producing it was a monzonite, which is initially quartz-poor. It seems, then, that rocks which resist assimilation by an invading magma will probably remain in their original position during intrusion, especially if the magma is not activated by tectonic forces. Thus where wall rocks and intrusive have similar bulk compositions, roof pendants might be expected.

<u>Size of the Residual Area</u>: In the original definition of the term 'roof pendant', Daly (1906, p. 336) mentioned size as a criterion for the discrimination of xenoliths and roof pendants. It seems to the writer that size is relatively unimportant. It is granted that very large areas, such as the Mine area of the Kernville series would be logically interpreted as roof pendants, just as very small areas, e.g. photograph, p. 155, (this thesis), would be considered xenoliths. The intermediate cases, must, it seems to the writer, be determined on other criteria. It seems important to search, therefore, for further criteria for distinction.

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1 This would be denied by Bowen (1922, p. 513), who has experimentally shown that dissolving of inclusions is expected only when the inclusion contains minerals listed lower in his "reaction series". Thus, applying to the case to be discussed, an invading granodiorite would be expected to dissolve quartz-rich inclusions, and not basaltic inclusions. Fenner (1929, p. 225), on the other hand, found rhyolite flows in Yellowstone Park which had melted basalt inclusions. In the Kernville area, it is certain that the experimental data of Bowen is contradicted in this case, at least, as the presence of the large quartzite septa show.

Summary.

The writer believes the criteria outlined above to be valid and feels that their application will provide more positive results where indefiniteness now prevails. Furthermore, it seems likely that new and better criteria may be added to these as positive recognition of the character of residuals in intrusives is accomplished.

Special Features of the Plutonic Rocks.

Introduction.

In the Sacatar quartz-diorite and Isabella granodiorite, occur dark inclusions which deserve special mention. The "contaminated phase" of the Sacatar quartz-diorite has been shown to include countless dark inclusions. (Figures 37 & 38) The Isabella granodiorite contains occasional dark inclusions of small size. Inclusions in the two units will be discussed separately.

Dark Inclusions in the Sacatar Quartz-diorite.

Description.

Megascopically, the inclusions are from a fraction of an inch to more than a foot in length. They occur in nests, groups, and in uniformly distributed masses over large areas. They are fine-grained, equigranular, with much hornblende and biotite.

Microscopically the inclusions are composed of andesine (An_{40}), about 80%; biotite and hornblende, about 18%; with the former in slight excess. Apatite, sphene, and a few grains of pyrite make up the remainder. Most crystals are subhedral, with poikilitic intergrowths of the feldspar and mafic minerals.

Origin.

Previous Interpretations.

The problem of the origin of dark inclusions has long been a pertinent one in geologic discussions. Of late it has received considerable attention, especially since the work of Cloos has indicated their importance in structural studies of batholiths. An elaborate paper by Pabst (1928) seemed to give impetus to the study of the problem and several papers have since appeared.

Pabst (1928) describes many dark inclusions in the granodiorites of the Sierra. He discusses theories of origin; and, although he admits the fact that their origin is still an open question, he believes those of the Sierra are probably autoliths. The inclusions occurring in the granodiorites described by Pabst closely resemble those of the Kernville area.

Nockolds (1932) has described inclusions in granite from Bibette Head, Alderney, which he believes are xenoliths of mafic material caught up during intrusion into older diorites.

Hurlbut (1935) reports dark inclusions in a tonalite from Southern California. He discusses hypotheses for their origin, and concludes that those in the area studied by him are the result of intrusion of tonalite into gabbro. He thus concludes that the inclusions are xenoliths.

The hypothesis of origin by liquation, advanced by numerous workers in an earlier literature is, at the present time, in disfavor.

Suggested Origin in the Kernville Region.

In the Kernville area, the Summit gabbro has textural and mineralogical characteristics similar to the dark inclusions. It is suggested that the inclusions originated by stoping of the earlier consolidated gabbroic mass. This is further supported by the constant association in space and time of the gabbro and the quartz-diorite.

The evidence seems to indicate that, in the Kernville region at least, basic enclosures are xenolithic rather than autolithic, as suggested by Pabst for some of the granodiorites of the Sierra Nevada.

Dark Inclusions in the Isabella Granodiorite.

Inclusions are rare in the facies of the Sierran granodiorite found in the area studied by the writer. The few that are found occur in widely separated places, and are of small size. A thin section of one taken at random contains the same minerals as the enclosing rock, with an aplitic texture. The inclusion is a slightly darker gray than the host rock. These characteristics seem to support the conclusion that the few isolated enclosures are autolithic. These in the Kernville region are distinctly lower in mafic mineral percentages than those studied by Pabst; average dark mineral percentages are three or less.

Development of Structures in the Intrusive Rocks.

Internal structures are almost lacking in the Summit gabbro and the Sacatar quartz-diorite. Linear parallelism of the gabbroic inclusions found in the quartz-diorite, and occasional foliation in the quartz-diorite and gabbro is all that is seen. These simulate structures formed by pressure during magmatic consolidation. Sufficient outcrops showing these structures have not been seen to prove this speculation.

In the granodiorite masses, there are several structural units: (1) Linear parallelism of the minerals of the rock. (2) Alignment of inclusions. (3) Development of sheet jointing.

The linear parallelism of the minerals is commonly reflected by the quartz (in alaskites) which occurs in the foliated facies in large anhedral gray glassy grains, with a linear parallelism caused by flowage during consolidation. Such phases are well shown in parts of the intrusive, but their total areal extent is very small. Parallelism of the platy minerals is unusual, even in those facies in which they are more prevalent; no dark minerals are found in the facies showing the pronounced linear parallelism of quartz.

Very few inclusions are found in the Isabella granodiorite. The few that are seem confined entirely to the margins, near the larger roof pendants of the Kernville series. Flow structures are often associated with these enclosures, due in all probability to drag along contacts during emplacement of the batholith.

Sheet jointing is well developed in the granodiorite. Some good exposures are found in the Domelands, but the best is to the south in the Bartolas country. Its origin is commonly ascribed to release of pressure by the removal of a heavy cover of overlying materials.

Volcanic Rocks.

Descriptive Section.

Volcanic Rocks.

Descriptive Section.

Introduction.

In the southern Sierra there have been few reported occurrences of volcanic rocks. Those to be described are the first known in this part of the range. Although these rocks do not areally constitute a major part of the geology, they are, nevertheless, extremely interesting, and the writer has spent a considerable time in deciphering the problems involved in their origin. Among the types found are: olivine basalts, olivine andesites, hornblende trachytes, quartz-olivine basalts, and basalts in which iddingsite is the chief mineral that can be recognized with assurance.

Previous Literature.

In the Kernville region, Miller (1931, p. 353) reports the occurrence of

> "A small area of andesite . . . . two and two-thirds miles a little west of north of Weldon. This andesite seems to be in the form of an irregular dike cutting porphyritic granodiorite."

and further that

> "Waterworn pebbles of a similar material in a nearby wash prove that more andesite exists, or formerly existed farther to the north, but no exposure was found."

No flow rocks in the region have ever been reported.

Lawson (1904, p. 300) describes basaltic cones and flows in the Olancha quadrangle. A petrographic description of some of these rocks is given by Knopf, in Lawson (1904, p. 374-6). Knopf (1918, p. 73) describes the volcanic cones of Templeton and Monachee meadows in the Olancha quadrangle.

Areal Distribution.

The volcanic rocks occur in disconnected units mostly in the west central and southern parts of the area. They vary in type, show different petrologic sequences, and markedly different structure. Seven areas are to be included in this discussion. From south to north, they are: The Bartolas lavas, north of the South Fork valley; the Taylor meadow group, on the northern margin of the Taylor creek drainage; Black mountain, north of the Taylor meadow unit, but in Manter creek drainage; East of White dome unit, occupying the summit of 7281 mountain; the Woodpecker group, on the headwaters of Trout creek; and the Niggerhead. At the northern edge of the quadrangle is a basaltic flow within the Kern canyon.

The Bartolas Group.

Introduction.

The Bartolas group consists of five isolated areas, four of which were at one time connected and which have now been separated by erosion. This is known to be true because of the similar attitude and composition of these four units; also by their thickness, structure, and general areal pattern. The fifth area of the group occurs on the summit of 8100 hill; it differs in occurrence and lithology from the other four parts. It will, therefore, be considered separately.

Bartolas Creek Unit.

General Statement.

On the higher summits of the gently undulating Bartolas oldland are four separated, but closely related, flows of quartz-basalt, from 100 to 150 feet thick. These flows are difficult to discover on reconnaissance as the region is heavily wooded, and the volcanic areas small. On the first (reconnaissance) trip into the area, one flow of the Bartolas creek unit was overlooked.

Megascopic Description.

Megascopically, the rocks are aphanitic, except for occasional globular of lenticular masses of gray, glassy quartz, up to one-quarter of an inch in diameter. No other minerals are visible with the twenty power lens. The rock is dense, black, and platy; the field name assigned was basalt. (Figure 47.)

Microscopic Description.

Microscopically, the rock is so fine-grained that it is difficult to determine much more than was noted megascopically. A few grains of euhedral olivine, as small phenocrysts, occur, along with lath-like, small subhedral crystals of the monoclinic pyroxene, pigeonite. Some calcite occurs, probably indicating that calcic plagioclase makes up the lath-like minute crystals of the microcrystalline ground mass. No positive determination of the plagioclase could be made. The average specimen shows a eutaxitic structure. Quartz was not found in the ground mass. The rock is classed as a quartz-basalt.

8100 Hill.

This volcanic unit is the westernmost of the Bartolas group. It shows different lithology and occurrence from other areas.

Megascopic Descriptions: Stratigraphically there are three members in this unit arranged in the following order:

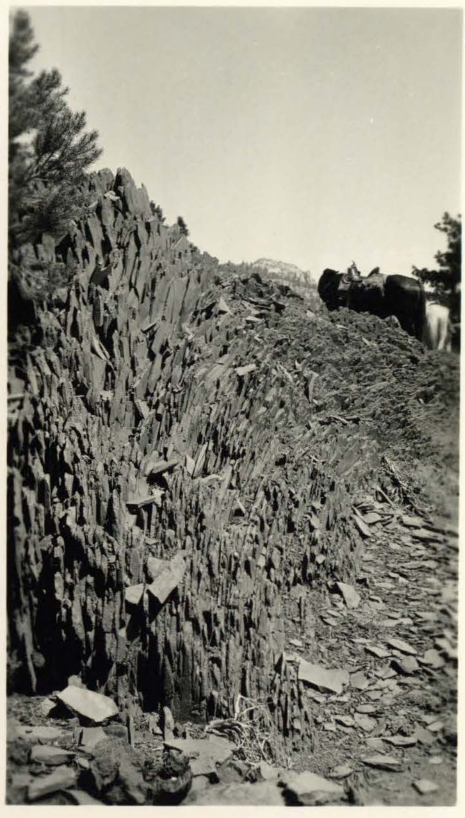

Figure 47. Platy flow structure in quartz-basalt of Bartolas creek group, Bartolas flats.

(1) At the top occurs a light-colored, gray, pumiceous lava, containing very small crystals of an amphibole (identified in the field as hornblende) and a few flakes of biotite. (Figure 48.) The similarity in hand specimen of this rock to the flows of hornblende andesite found in the Sacramento river canyon at the base of Mount Shasta led the writer to class the rock as such in the field. The thickness of this flow is estimated at less than fifty feet.

(2) Below the pumiceous lava occurs a red, banded, basaltic aphanite, with no visible mineral constituents. It was tentatively identified on the basis of color, structure, and texture, as basalt. The thickness of this unit could not be estimated, due to the talus and brush cover, but it is thicker by far than the top pumiceous flow.

(3) The lowest unit is a black, massive basaltic aphanite, about 100 feet thick. It has distinct platy flow structure which appears to dip into the hill at all points. Glassy facies of this flow were observed in float.

Microscopic Description: The upper unit of 8100 hill shows in thin section abundant euhedral crystals of orthoclase, in rectangular laths, and six-sided sections. The orthoclase is almost uniformly twinned on the Karlsbad law. The pseudo-hexagonal cross-sections seem to have centers of overlapping biotite plates, around which some of the orthoclase has crystallized. The orthoclase shows strong strain shadows and is occasionally zoned. A few grains of plagioclase are present. They make up a very small percentage of the rock. A few flakes of euhedral biotite occur, besides those surrounded by orthoclase. Basaltic hornblende makes up the bulk of the mafic material; but it occupies less than five per cent of the volumetric total. The grains of hornblende are subhedral, of deep brownish color and pleochroism,

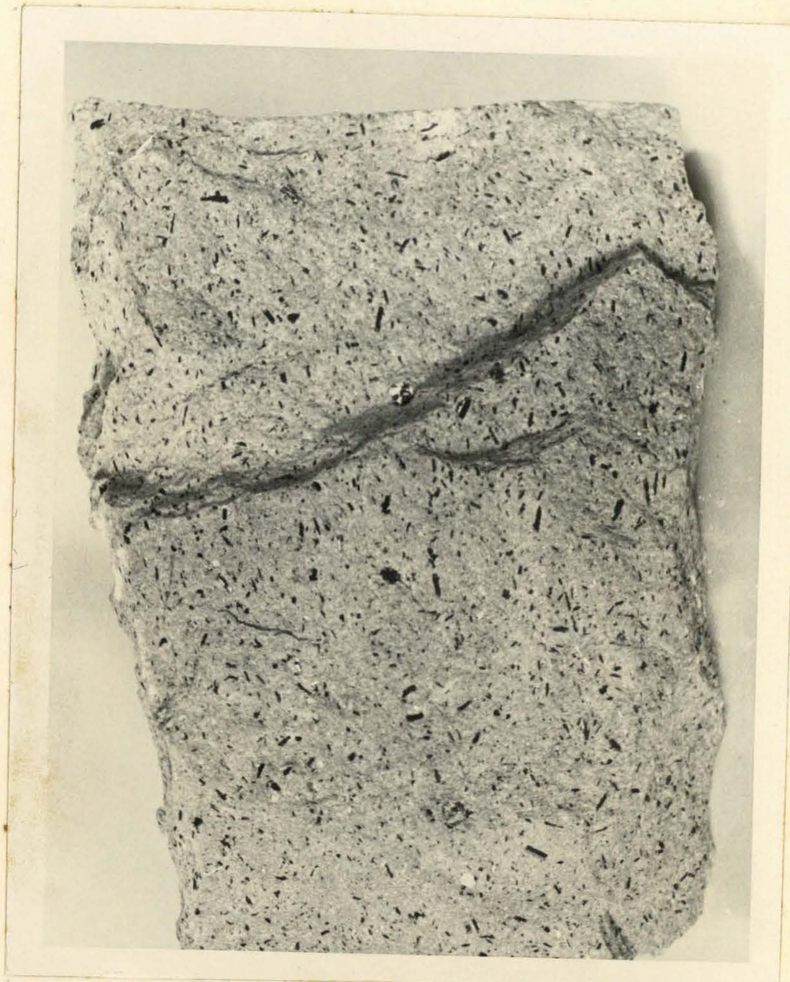

Figure 48. Pumiceous hornblende trachyte of 8100 hill, Bartolas.

with an extinction angle of ten degrees. The ground mass is composed of very fine-grained, needle-like, crystals interlocking in mat-like form, with microcrystalline texture. The rock is holocrystalline, with an orthophyric texture. It is classed as an hornblende trachyte.

The central unit consists of grains of iddingsite, in large euhedral (olivine form) individuals, whose cores consist of unaltered olivine grains. The iddingsite is of deep brown color, is slightly pleochroic with strong dispersion, and shows the characteristic concentration of limonite and hematite around each of the iddingsite individuals. Magnetite is present in very small crystals. Laths of a mineral of moderate to low birefringence, in nondeterminable form, is probably plagioclase. These minerals, composing a small percentage of the rock, are embedded in a microcrystalline matrix. The texture is holocrystalline; the rock is classed as an olivine basalt.

The basal unit is composed of phenocrysts of olivine; magnetite; and extremely fine laths, probably plagioclase; and quartz, with resorbed boundaries. The texture is holocrystalline. The rock is classed as a quartz-olivine basalt.

Taylor Meadow Group.

Introduction.

The Taylor meadow group consists of two closely associated areas. They are called Big Table mountain and Little Table mountain. Although the two areas are close together, they show differences that make it best to discuss them separately.

Big Table Mountain.

A single unit, fully 200 feet thick, of massive basaltic aphanite comprises this flow. No minerals are visible, and flow structure is rare;

Figure 49. Big Table mountain, looking north from Bartolas flats.

Figure 50. Big Table mountain as seen from south end of Long valley, looking west across the canyon of the South Fork.

the base of the flow is agglomeratic in character. Microscopically there can be distinguished olivine and plagioclase laths, with possibly some magnetite. The rock is holocrystalline, with a pilotaxitic texture. It is classed as an olivine basalt.

Little Table Mountain.

Just west of Big Table mountain, separated from it by a canyon about 300 feet deep, lies an irregular cap-like area of volcanic rocks, which although closely associated with the olivine andesite of the neighboring mountain, show textural relations which are unique. The rock is light colored, with numerous coarse lath-like diabasic areas, composed apparently of plagioclase. These are surrounded by finer-grained areas, in which some olivine can be detected. Large inclusions of Isabella granodiorite occur heterogeneously throughout this flow.

The average flow rock of Little Table mountain contains olivine (altered to iddingsite), magnetite, and pigeonite phenocrysts, and lath-like crystals, probably plagioclase. It probably is an olivine basalt.

A thin section across the contact of the fine-grained and coarse-grained facies of this rock shows, in the fine-grained part: olivine, iddingsite, plagioclase, magnetite, and pigeonite, in holocrystalline, pilotaxitic intergrowth. The coarse-grained part shows: coarsely twinned calcic plagioclase, about bytownite (An_{80}), olivine, with strong iddingsite alteration, and titaniferous augite. Laths of magnetite, much the shape of plagioclase laths, also occur. Myriads of apatite crystals are embedded in the plagioclase. All of the essential constituents, plagioclase, magnetite, augite, and olivine are in poikilitic intergrowth. The diabasic texture indicates a hypabyssal origin for the coarse-grained parts. (See below p. 167)

Figure 51. Looking northwest across Black mountain flow, as seen from summit of Little Table mountain.

Black Mountain.

Within the Black mountain unit are several rock types, including scoriaceous facies. The average rock, a black aphanite, is classed as an olivine basalt. Microscopically it shows abundant phenocrysts of olivine, a very few plagioclase (labradorite?) phenocrysts, and magnetite. The ground mass is holocrystalline, composed chiefly of olivine and fine needle-like laths, probably of plagioclase. Olivine is far more abundant in this unit than in any other. Inclusions of granodiorite are also found in this series. The Black mountain unit lies by unconformity on a basement of Isabella granodiorite. It occurs as a flow, from 150 to 200 feet thick.

East of White Dome Flow.

On the east side of the South Fork of the Kern river occurs a very large flow, with an areal extent of nearly three-quarters of a square mile, and 250 feet thick. It occupies the summit of 7281 mountain. The panorama view (plate XIII) shows well the position of this flow. The typical rock is a black aphanite. Microscopically it contains olivine, iddingsite, and a considerable amount of calcite, which perhaps indicates the presence of calcic plagioclase. Iddingsite is well developed. The rock is holocrystalline, pilotaxitic. It is an olivine basalt. Some inclusions of Isabella granodiorite were also found in this unit.

Woodpecker Group.

The Woodpecker unit is breached by the gorge of Trout creek, which separates into two areas what was at one time a continuous flow. (See geologic map.) The gorge at the point of separation is about 1500 feet deep.

The Woodpecker flow is 500 feet thick (figures 52, 53). It is nearly uniform from top to bottom except in agglomeratic zones near the base. A

Plate XIII.

Panorama view from Bald mountain (Olancha quadrangle), looking southeast. In west center foreground can be seen Woodpecker lava flow, occupying small hill, with bold, east-facing outcrops. In center, Trout creek oldland, lying north of the Domelands, which are seen in the middle distance. The flat-topped summit in the center background is East of White dome lava unit. Chimney peak in the east background. Total distance of view, east to west, twenty-five miles.

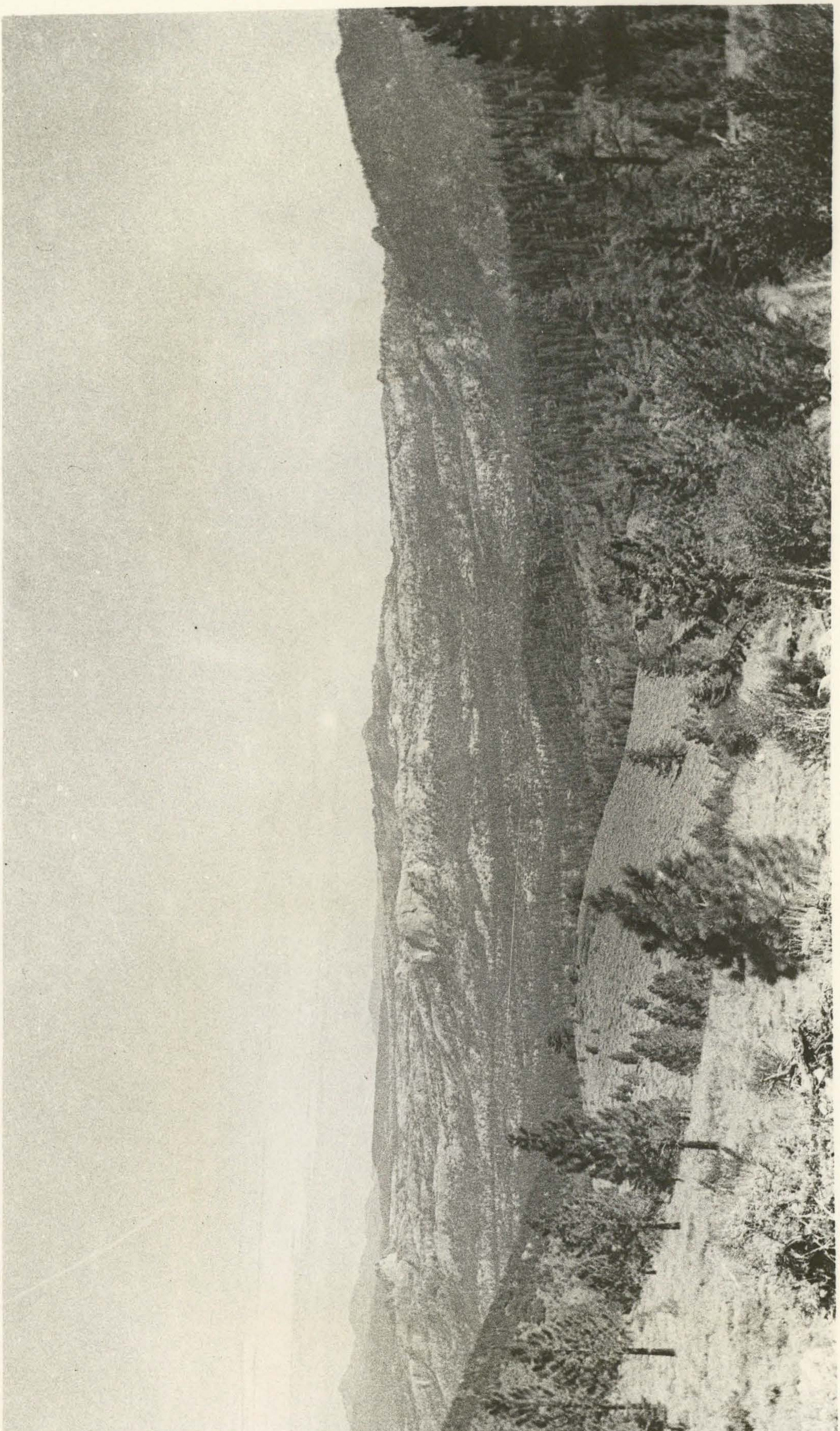

Figure 52. The Woodpecker flow, looking north. The Niggerhead in the far distance. Note grano-diorite-lava contact in Woodpecker unit.

Figure 53. Close-up of Woodpecker flow, looking at its east edge.

platy flow structure is well developed. The average rock is a grayish aphanite, weathering brick red. Microscopically, the grayish facies is composed of olivine as phenocrysts; and in the ground mass, laths of plagioclase; a pyroxene, either augite or pigeonite; and some olivine. The rock is holocrystalline, pilotaxitic. It is an olivine andesite.

The red phase has the same mineral composition, except that nearly all of the olivine has altered to iddingsite.

In the Woodpecker flows small inclusions of Isabella granodiorite are very common. This is particularly true of the western part of the flow.

The Niggerhead.

On the northern edge of the quadrangle there rises to an elevation of 7700 feet a large monolithic-like mass of olivine basalt. (Figure 85.) Since this mass is not entirely in the area of study, possibly it should not be included here. It is of very limited extent. If its extent ever was greater, there are no remnants. The nearest other volcanic material is the Woodpecker unit, more than five miles away.

Main Canyon of the Kern.

It has long been known that there were large flows along the main valley of the Kern (Lawson, 1904). These are the most extensive in the entire southern Sierra. They are now present in isolated areas up and down the river. The most southerly occurs on the boundary of the Kernville and Olancha quadrangles, about twenty-five miles north of Kernville. (Figure 55.) The southernmost tip extends into the area of detailed study. It is about fifty feet thick, and is composed of reddish vesicular basalt.

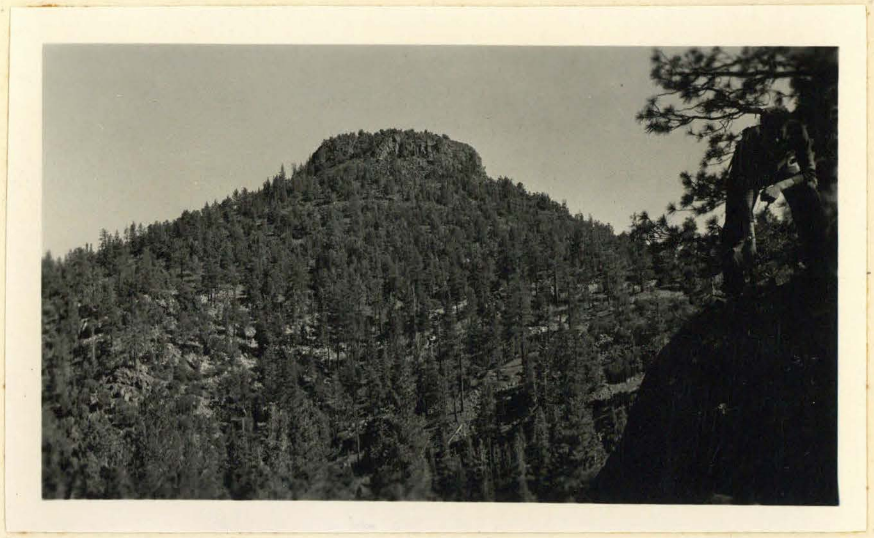

Figure 54. The Niggerhead, looking from the north.

Figure 55. Flows of the main valley of the Kern river. Looking west across the river. On boundary of the Olancha quadrangle.

Summary.

The distribution of the volcanic rocks of the southern Sierra is in scattered, isolated, small units, capping old erosional surfaces. They are of varied types; most of them seem to be flow occurrences.

Interpretive Section.

Interpretive Section.

Special Problems of the Volcanic Suite.

The Quartz in the Quartz-Basalts.

Introduction.

The occurrence of quartz in basalt has received considerable attention in the past decade, especially since the work of Bowen and others in the Geophysical Laboratory, of Washington, D. C., has brought out some of the physico-chemical laws which govern the occurrence of such a mineral in silica-poor rocks, and since more and more examples of such rocks are being described.

Historical Resume.

A classic occurrence of quartz-basalt is that of Cinder cone, Lassen Volcanic National park. The first description of this locality was by Diller (1887), and again by the same author in another paper (1891). The occurrence was further discussed by Day and Allen (1925, p. 36). The latest paper on Cinder cone is by Finch and Anderson (1930), where the complete history of Cinder cone is discussed, with a summary of the present status of the quartz-basalt problem.

The Occurrence of the Quartz.

Quartz has been observed in flows from Bartolas flats, Black mountain, and from Big Table mountain. The quartz occurs commonly in rounded granular aggregates, generally in aphanitic olivine basalt. (Figure 56.) The size of the quartz granules varies from several centimeters down to microscopic grains. No vesicular structures were found associated with the quartz. It is commonly iron-stained, and very glassy, with a pronounced conchoidal fracture. It has never been found associated with other minerals.

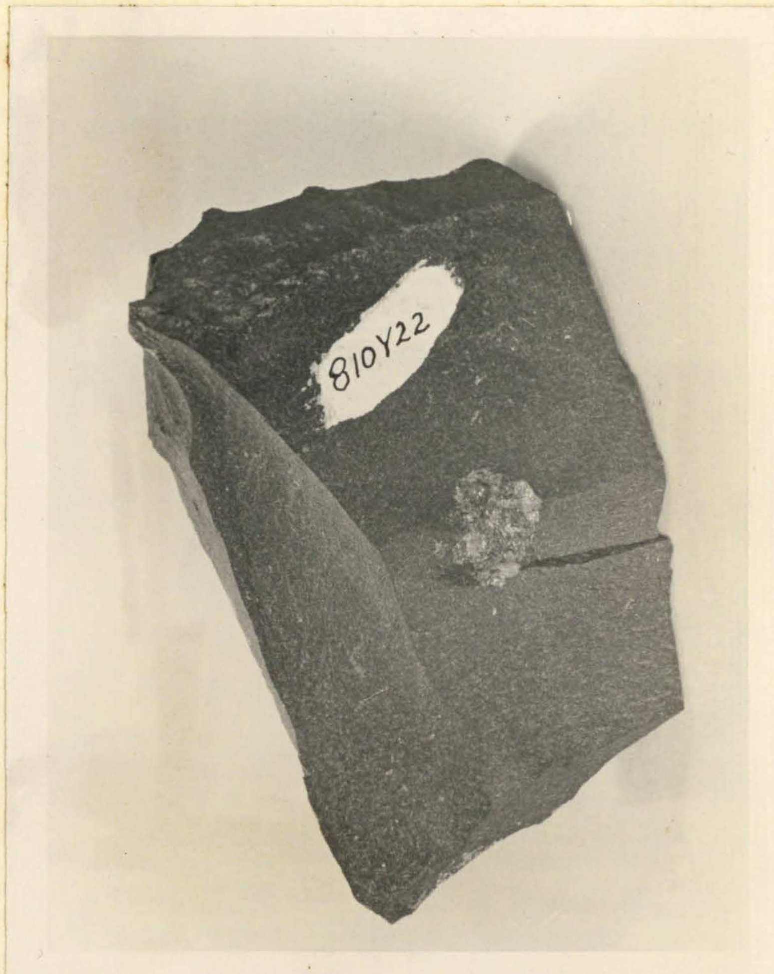

Figure 56. A quartz bleb in the basalt of the Bartolas creek group, Bartolas flats. About five miles due north of Onyx, California.

Hypotheses for the Origin of Quartz in Basalts.

Hypotheses for the origin of quartz in basalts have been discussed by numerous writers. Summaries of the present status of these hypotheses may be found in Finch and Anderson (1930, p. 259), and Daly (1933, p. 405). The following hypotheses have been advanced:

(1) Direct Crystallization from a Primary Magma. This hypothesis was offered by Diller (1891) for the Cinder cone occurrence, and by Wahl (1908, in Daly, 1933, p. 405) and Thomson (1912, in Daly, 1933, p. 405) for quartz diabase.

(2) Differentiates of Normal Basalts. This hypothesis is supported by Bowen (1928); he shows it to be sound on a physico-chemical basis. This hypothesis is implied by Day and Allen (1925), in their statements on the Cinder cone occurrence.

(3) The Gas Streaming Hypothesis. This hypothesis was advanced by Fenner (1926) to account for quartz-diabases.

(4) Hybridism. Harker (1909) suggested that quartz-basalt is a hybrid rock, produced by the crystallization of a hybrid magma. Finch and Anderson (1930, p. 273) advance this hypothesis for the Cinder cone occurrence.

(5) Moderate Contamination of Basaltic Magma. Daly (1933) suggests that solution of siliceous wall rock produces quartz-basalts.

The discussion to follow will attempt to show that selective solution of some of the constituents of granodiorite and granite xenoliths, included in a basaltic magma, produced quartz-basalts in the Kernville area. This hypothesis follows that of Daly, cited above. That other workers have suggested this process for the origin of quartz-rich basic rocks is shown by Daly, who says (1933, p. 435):

> "According to Stecher[1], the quartz diabases of the Firth of Forth region owe their free silica to solution of acid rock in diabasic liquid."

Granodiorite Xenoliths.

Within many of the flows of the Kernville region occur inclusions of Isabella granodiorite, the formation on which the most of the lavas were extruded.

Size of the Granodiorite Xenoliths: Recognizable granitic enclosures vary in size from one inch to two or three feet in diameter. They have been observed in three dimensions in only one case, in which average was two feet on a side. The smallest size given represents those that can be positively identified as granodiorite. Inclusions of much smaller size are composed mainly of quartz, with a few grains of altered feldspar. They are thought to be remnants of larger inclusions which have almost completely digested. Fresh specimens are hard to obtain from the massive basalts.

Shape of the Xenoliths: There is no regularity to the enclosures. Irregularly shaped masses are most typical, although spherical, ovoid, and elongate ones are common.

Distribution of the Xenoliths: The xenoliths have been observed in all flows in the Kernville area. In Big Table mountain only were large ones seen. They have no regular distribution. Where large vertical faces are exposed, inclusions range from the top to the bottom of the flow. In the Niggerhead, inclusions seem quite abundant near the base; in the Woodpecker flows they are commoner near the top.

Other Features: Within the xenoliths textural and mineralogical relations are the same as the parent rock. The larger enclosures are readily

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1 E. Stecher. Tschermak's Min. und Petr. Mitt., Vol. 9, 1888.

identified megascopically. Surrounding the xenoliths a semifused rim is occasionally present. Radiating outward from larger inclusions, one often finds tension cracks, generally in five or six directions. These probably have resulted from more rapid cooling of magma around the xenoliths.

Origin of the Xenoliths.

It is believed that the xenoliths were picked up by the lavas while rising through vents in the granodioritic rocks. Fragments were detached and included in the magma, and were carried out with the extrusion. After the first upward surge of magma, when the surface of deposition was reached, the xenolithic material probably rose upward somewhat in the flow[1], except where cooling was sufficiently rapid to prevent movement. This is probable because of the density differences of the olivine basalts and andesites, and the granitic rocks of the Isabella. It is evident that all of the xenoliths were not picked up from the surface of deposition as the magma flowed, because of the almost equal distribution throughout the flows. The greater concentration in some cases near the base indicates that some were picked up

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1 Daly (1933, p. 248) gives 2.74 as a mean density for liquid basalt of continental segments, and (p.47) 2.716 as the average density of solid granodiorite. Since the composition of the xenoliths in the flow rocks of the Kernville area are generally close to that of quartz-monzonite, their average density would tend to be slightly less than granodiorite (granite, average 2.667). Thus it would be generally true that xenolithic materials of this type would tend to rise in basaltic liquid. The range of density given by Daly for basaltic liquid and solid granitic-granodioritic xenoliths is such, however, that whether xenoliths sank or rose would depend largely on local factors. Careful determinations of densities of the granitic enclosures of the case in question might settle the question. Even with this information, the density of the basalt liquid in which the inclusions formed would have to be taken from data obtained elsewhere. No data regarding specific gravity of these rocks in the Kernville region can be presented at this time.